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(54) **THROUGHPUT ESTIMATION DEVICE**

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(74) *Attorney, Agent, or Firm* — Sughrue Mion, PLLC

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H04W 28/06	(2009.01)
H04W 24/08	(2009.01)
H04W 28/22	(2009.01)
H04W 24/10	(2009.01)

(52) **U.S. Cl.**

CPC **H04W 28/06** (2013.01); **H04W 24/08** (2013.01); **H04W 24/10** (2013.01); **H04W 28/22** (2013.01)

(58) **Field of Classification Search**

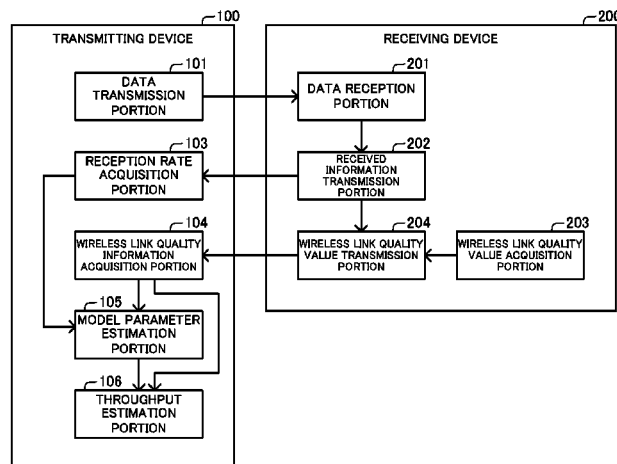
None

See application file for complete search history.

(57) **ABSTRACT**

A throughput estimation device **500** includes a wireless link quality information acquisition portion **501** acquiring wireless link quality information denoting a quality of a wireless link established between a mobile station and a base station on a mobile communication network, and a throughput estimation portion **502** estimating a throughput which is the amount for the mobile station to receive per unit time a data sent by a transmitting device connected communicably with the mobile station via the wireless link, based on the acquired wireless link quality information.

23 Claims, 25 Drawing Sheets



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Fig.1

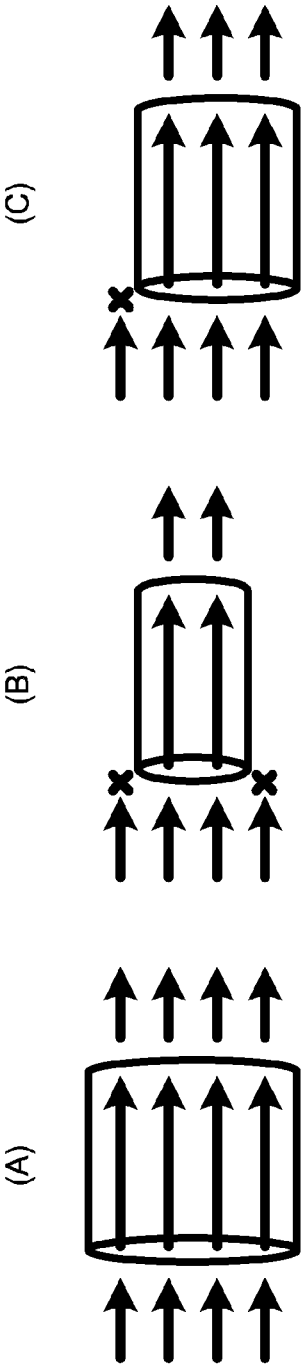


Fig.2

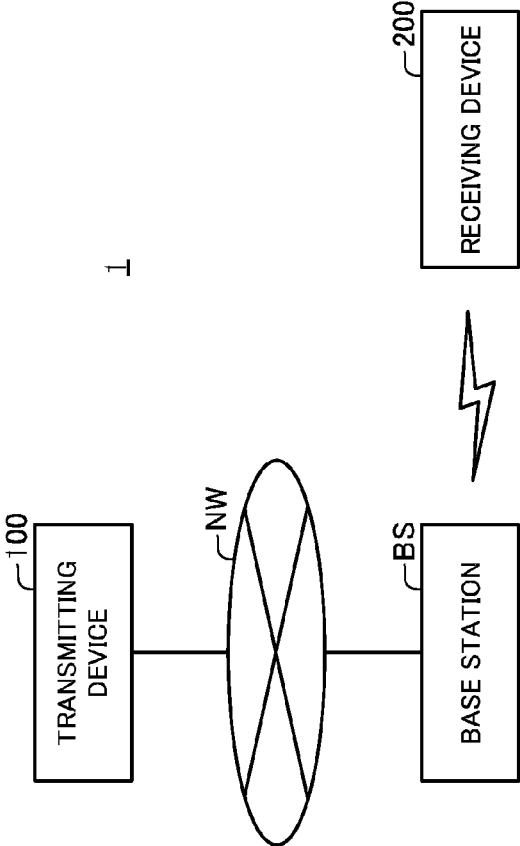


Fig.3

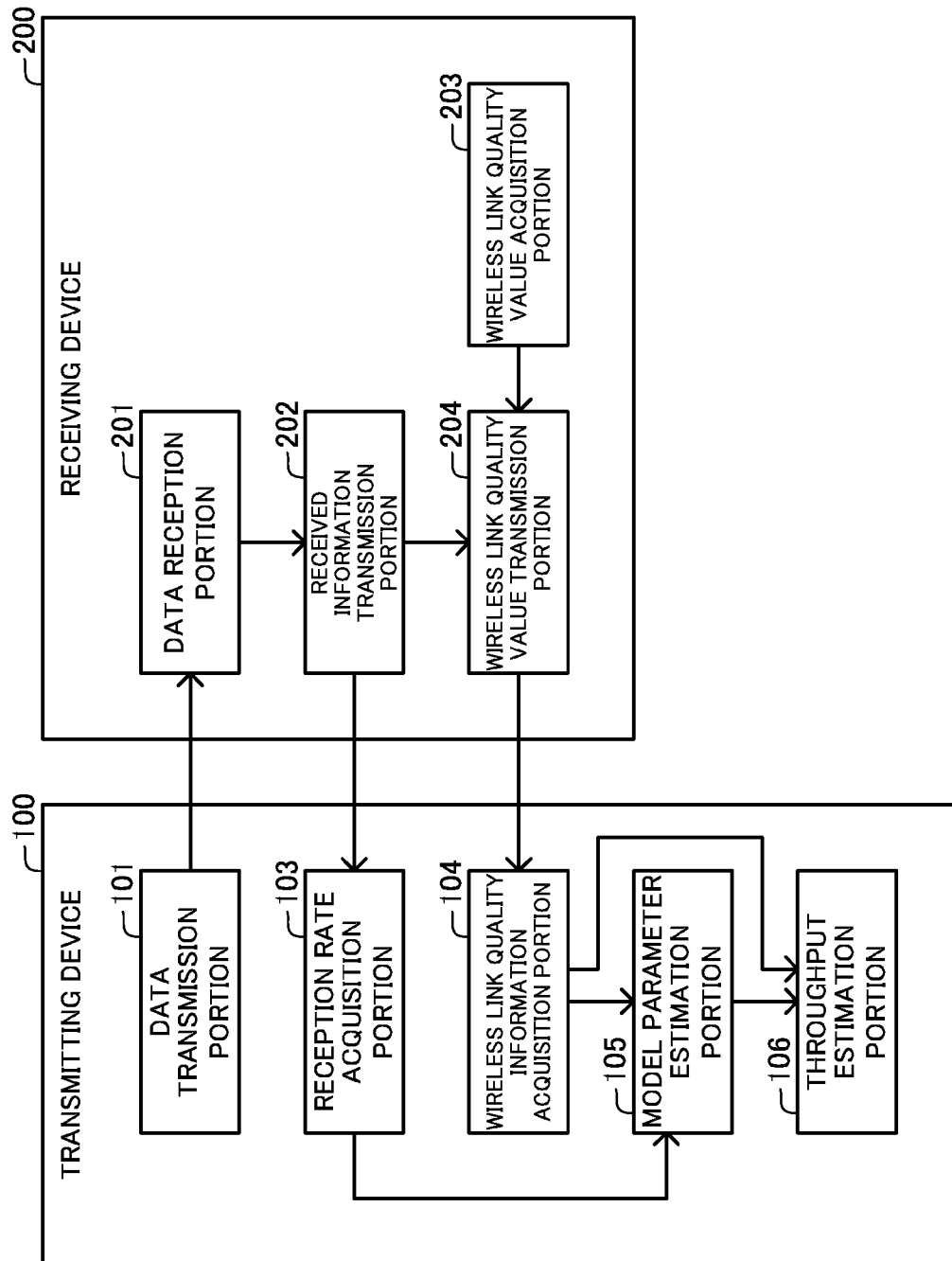


Fig.4

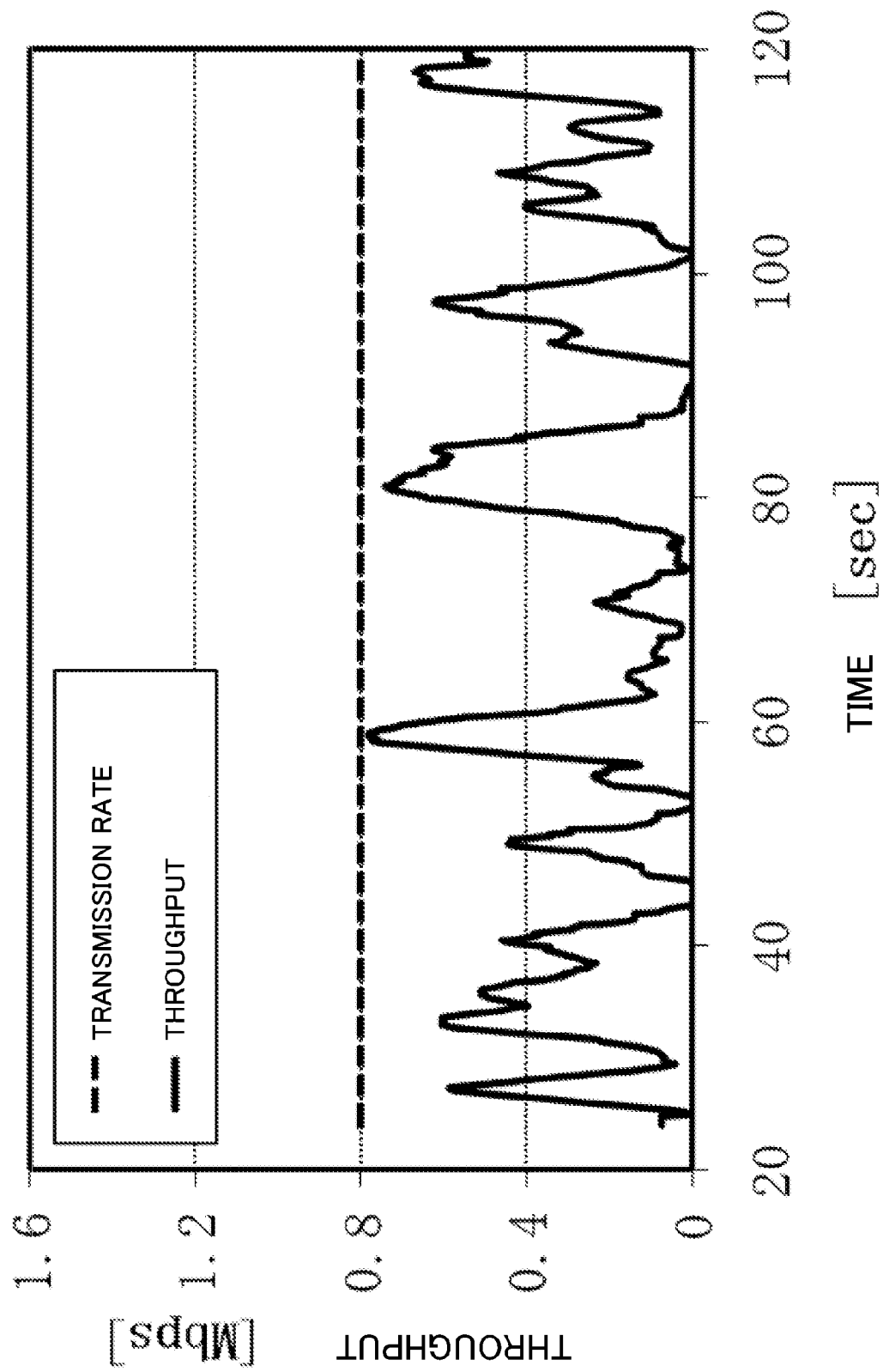


Fig.5

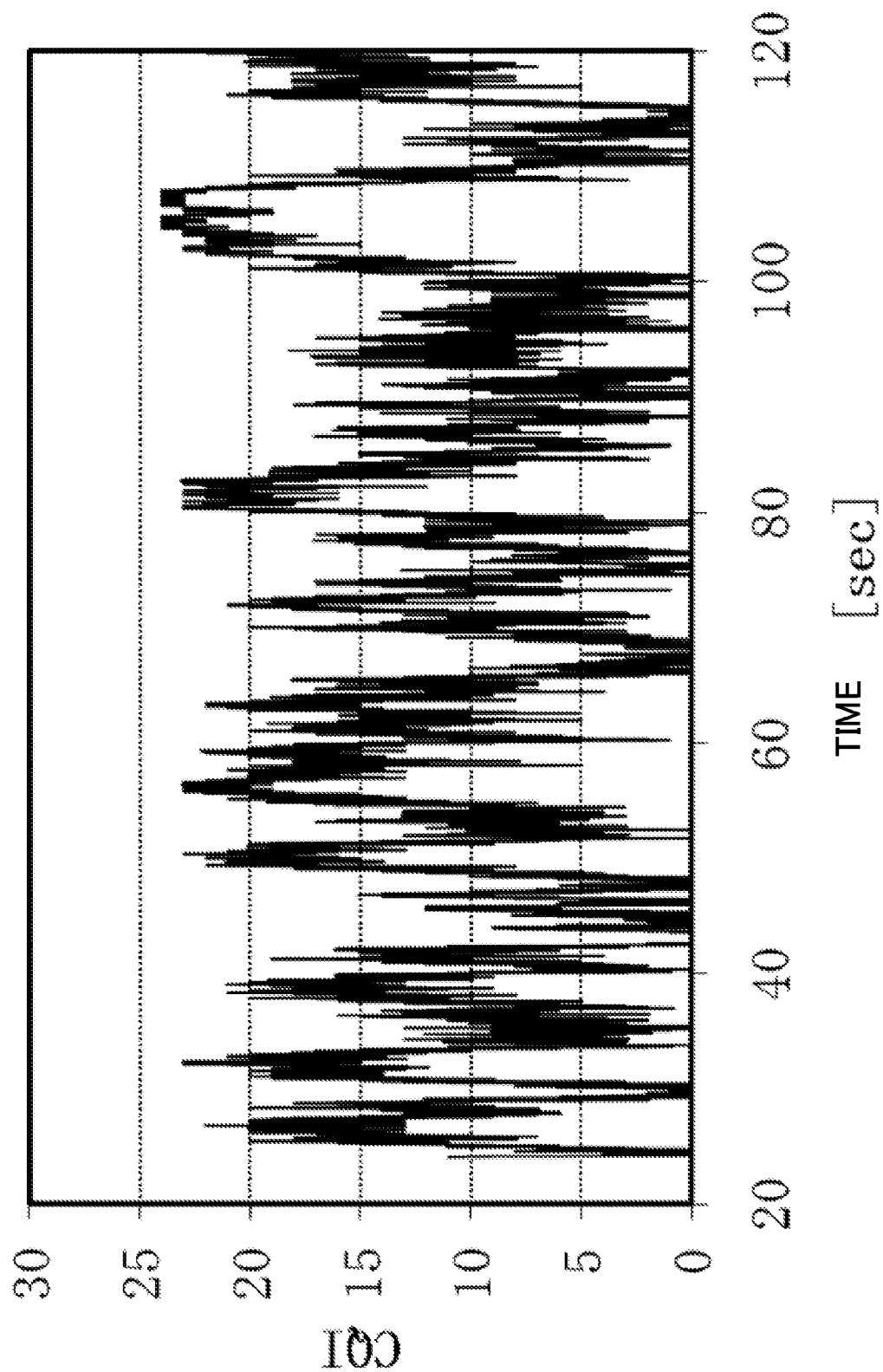


Fig. 6

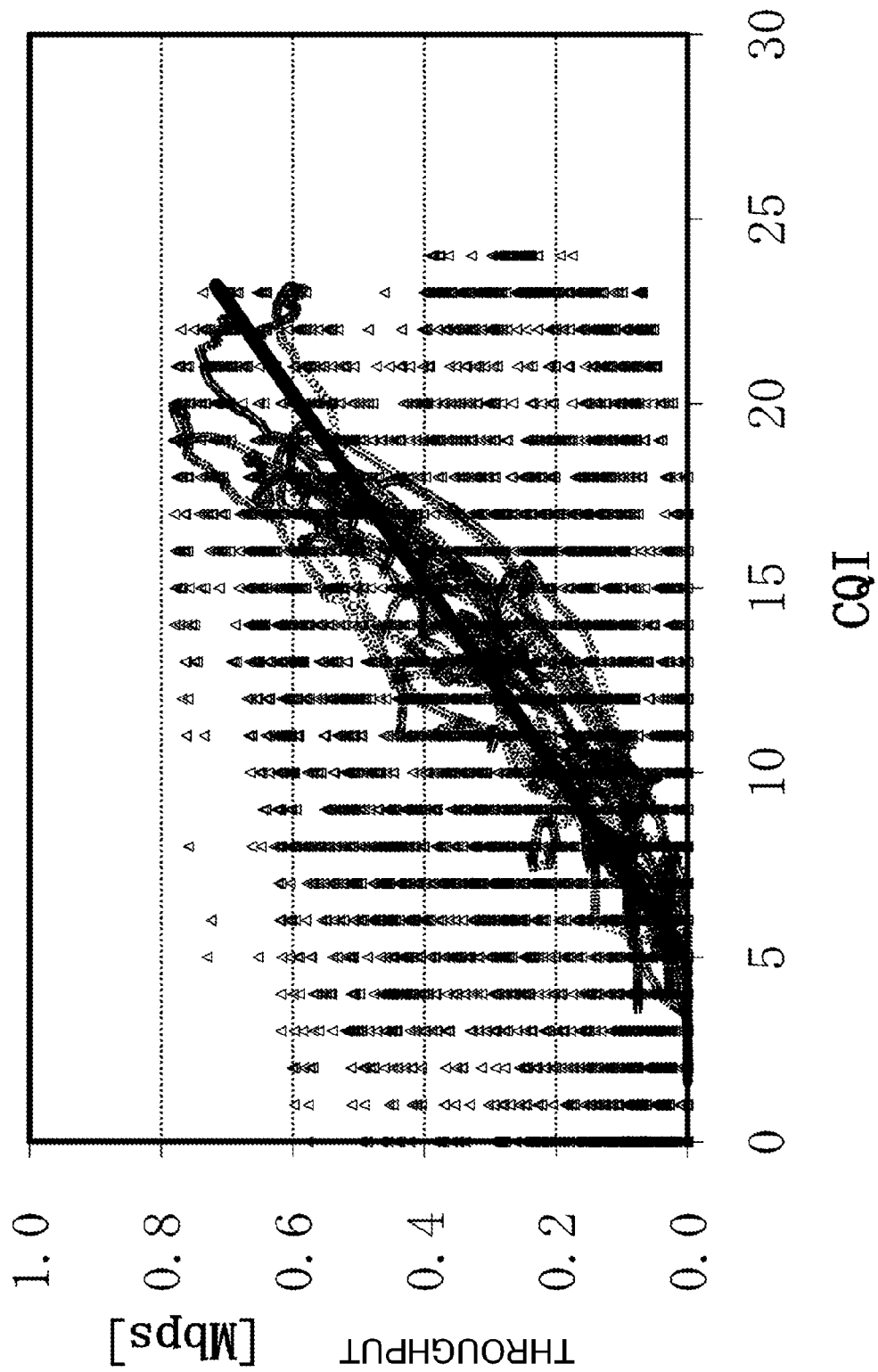


Fig.7

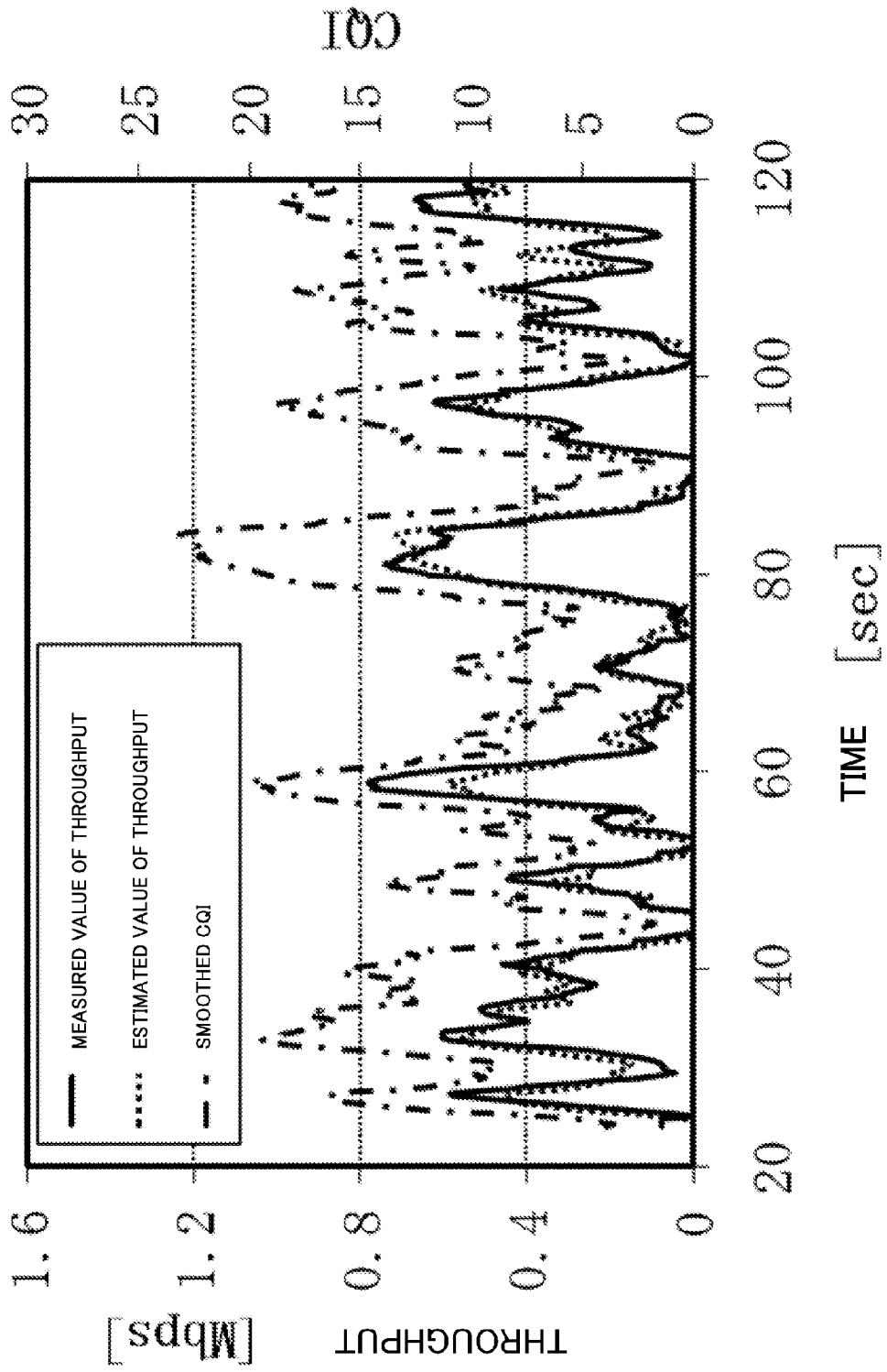


Fig. 8

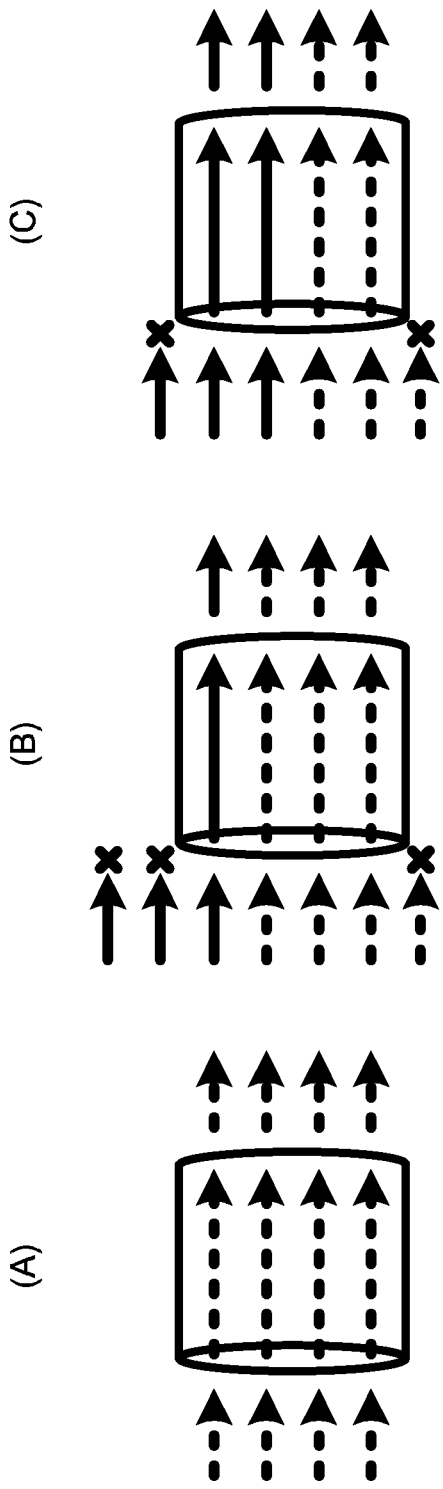


Fig.9

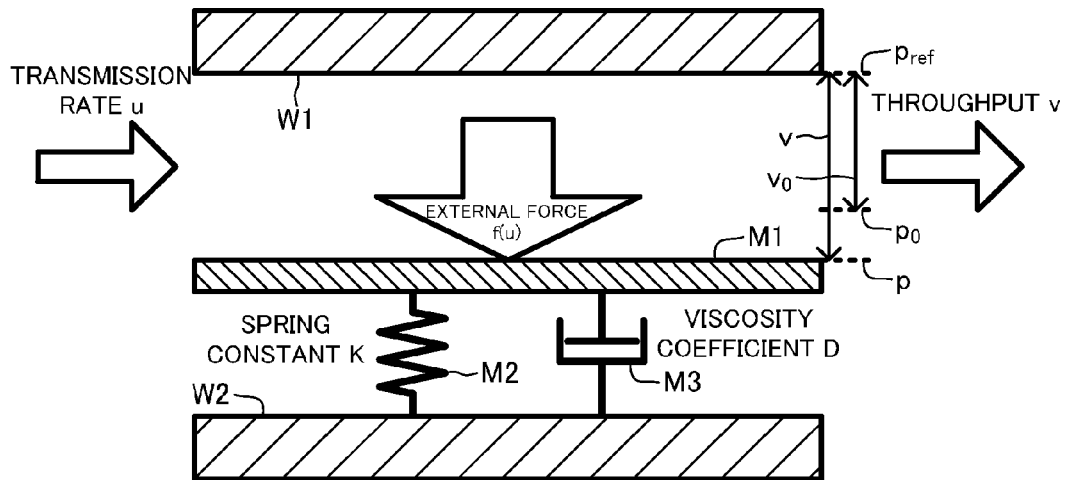


Fig.10

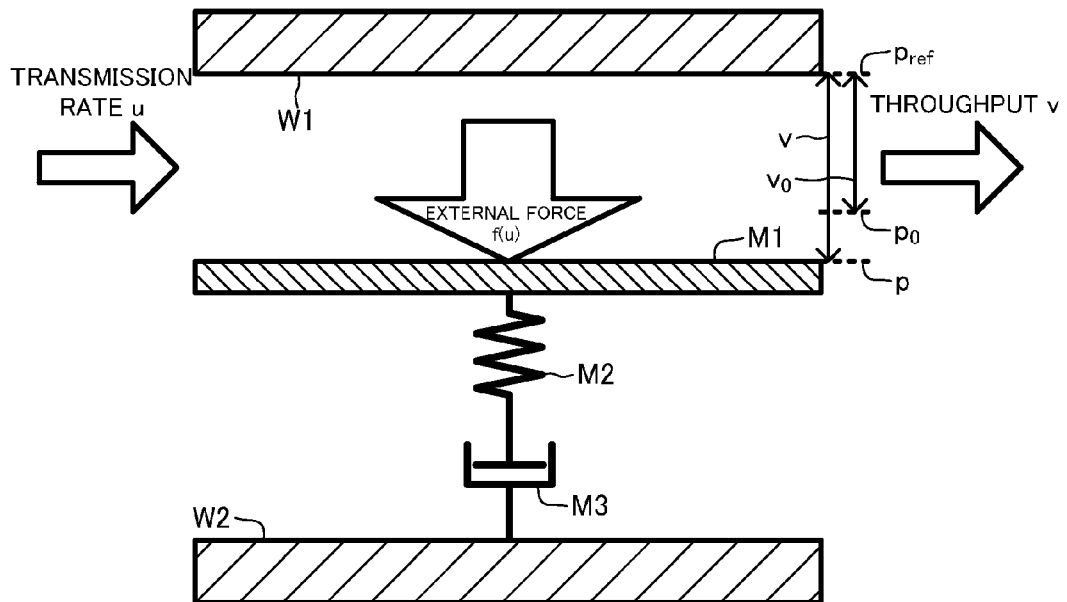


Fig.11

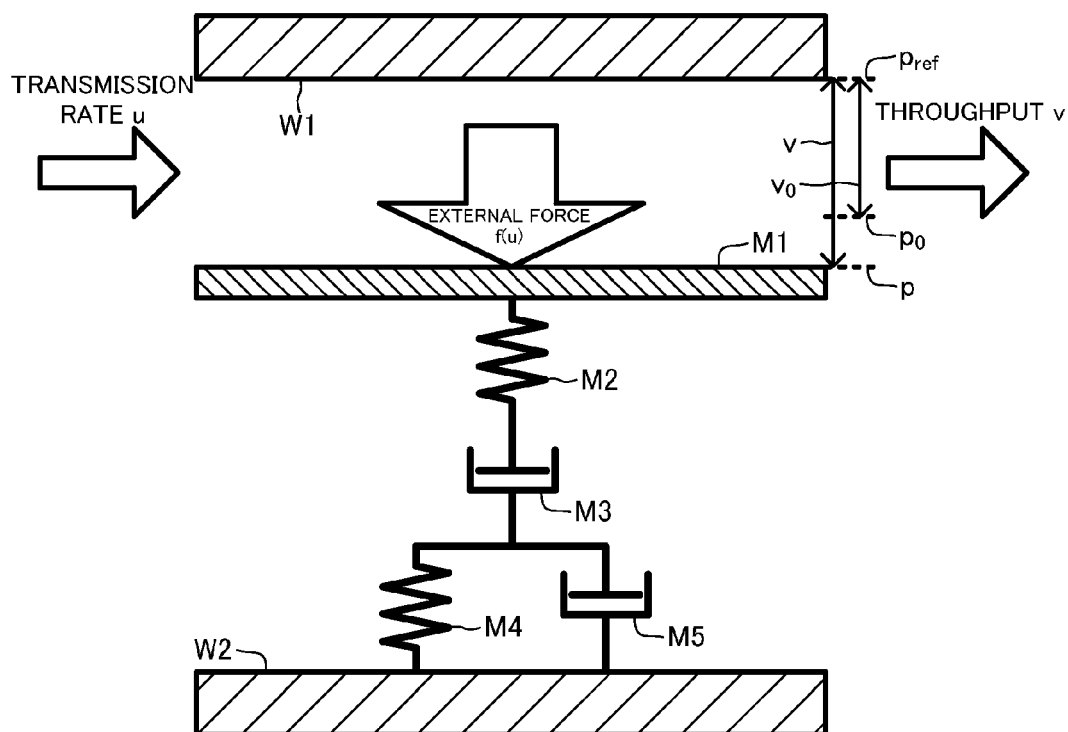


Fig.12

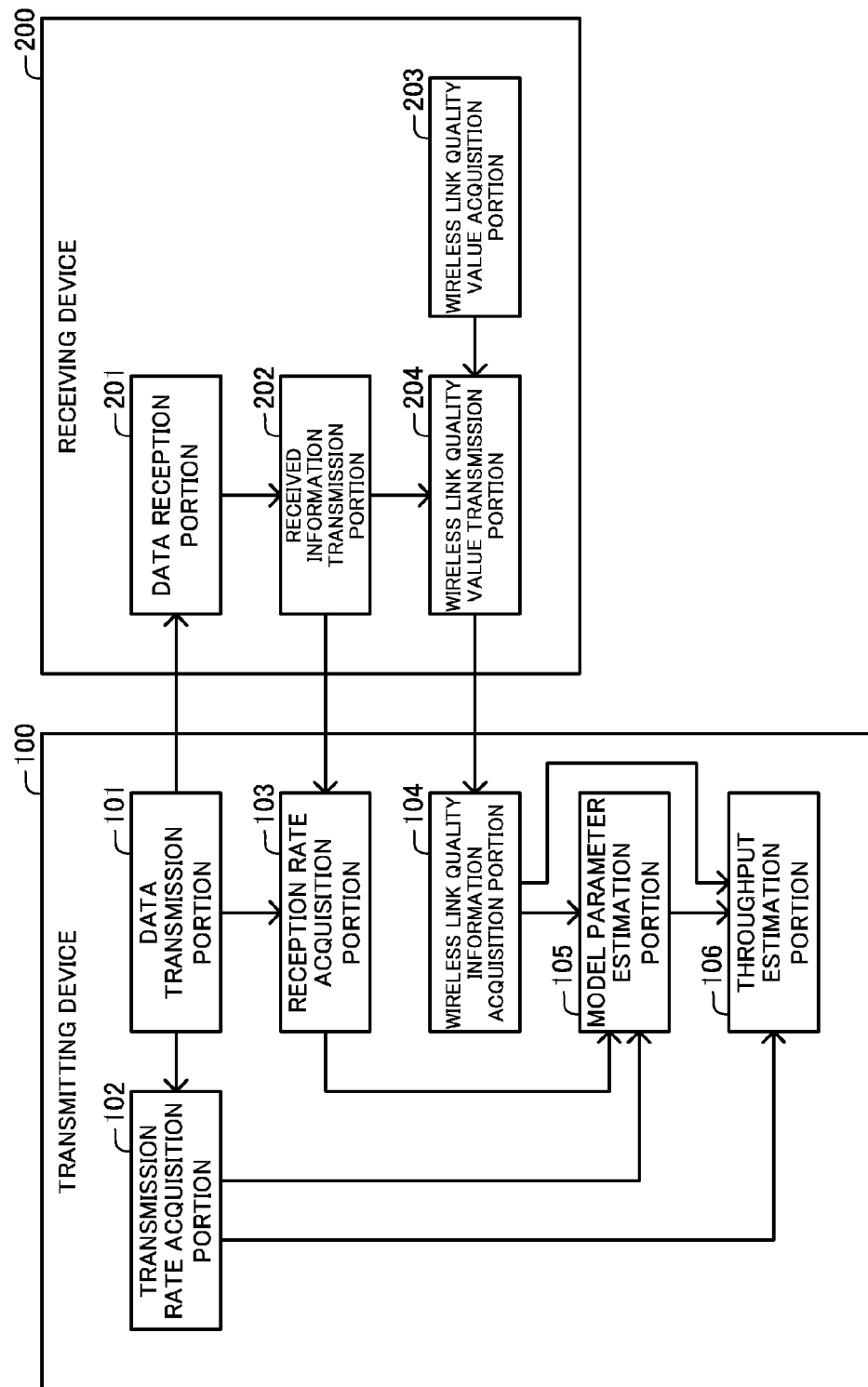


Fig.13

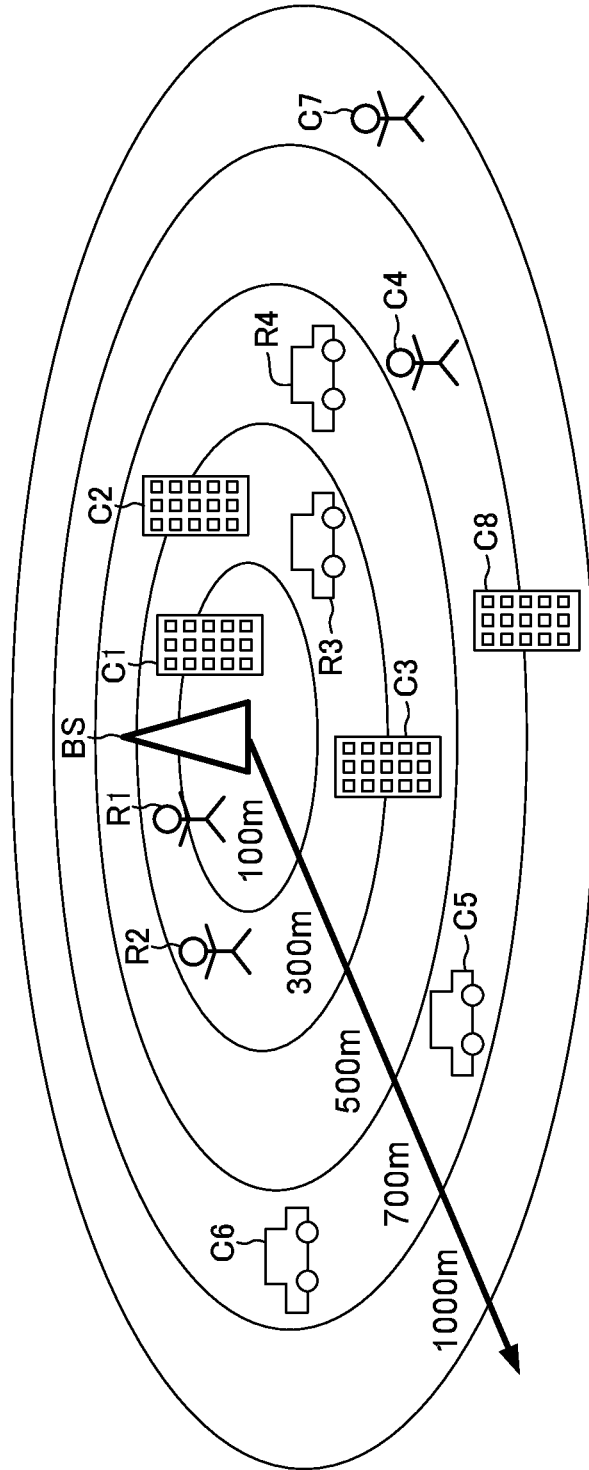


Fig.14

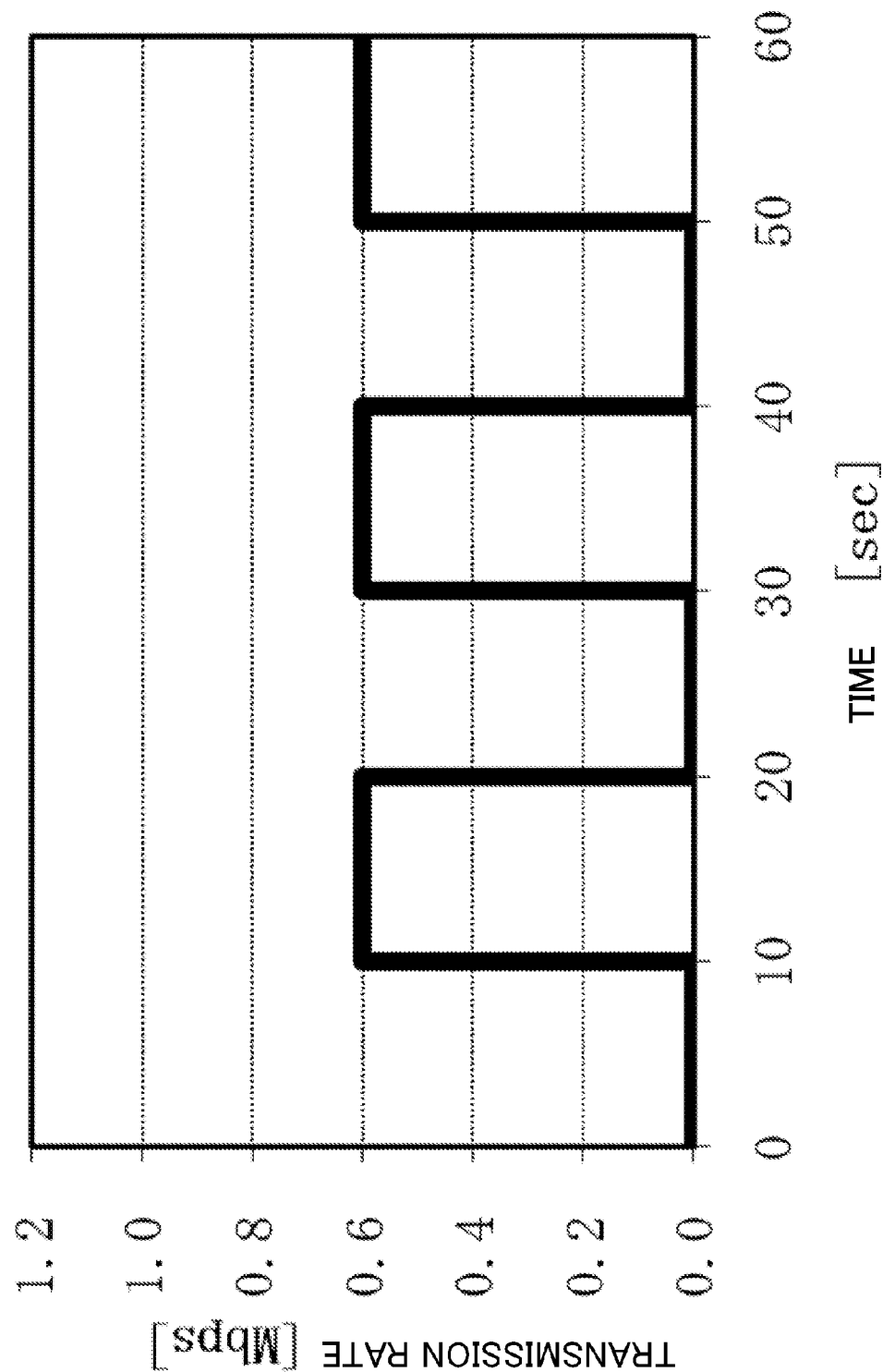


Fig.15

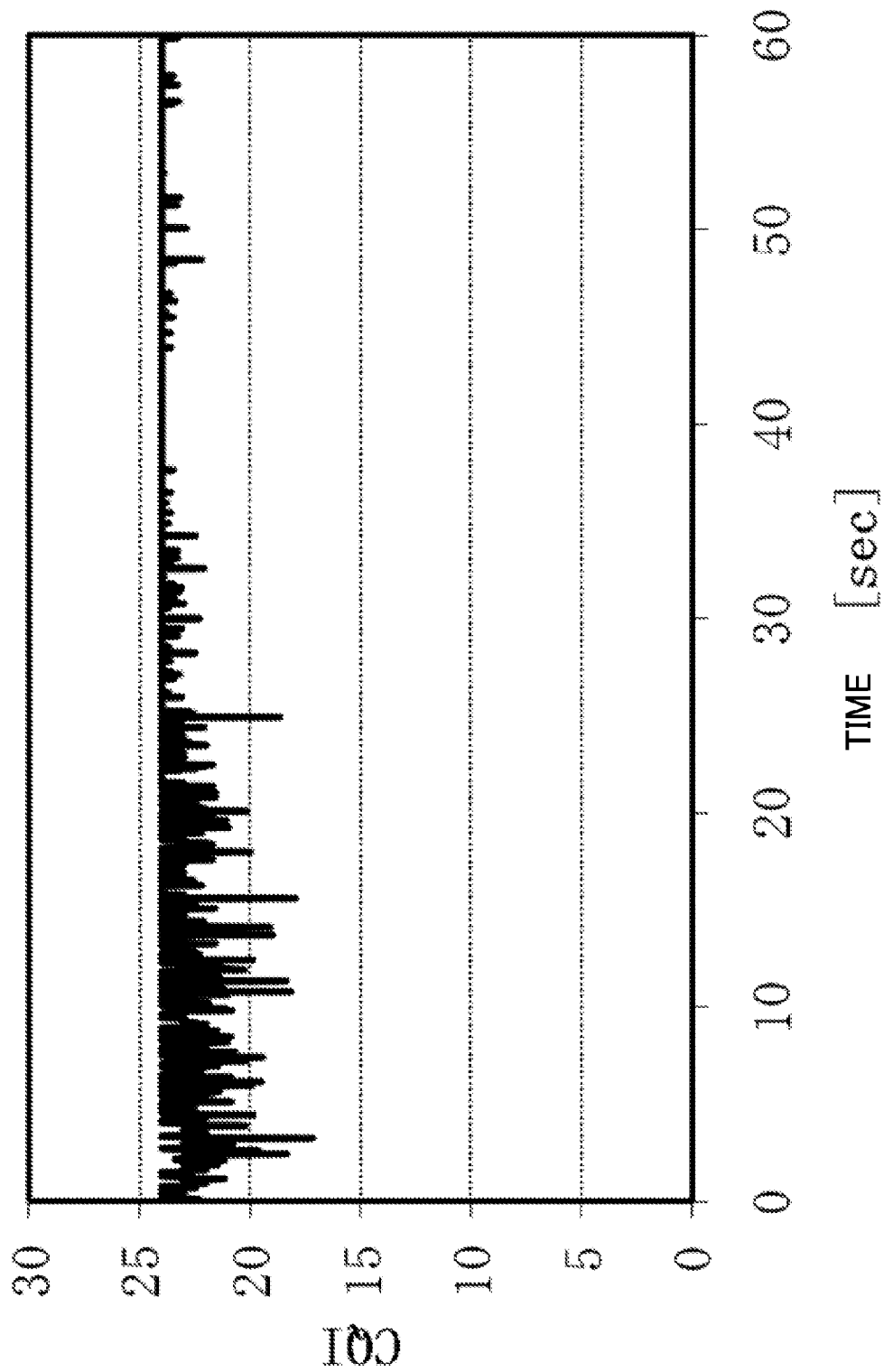


Fig.16

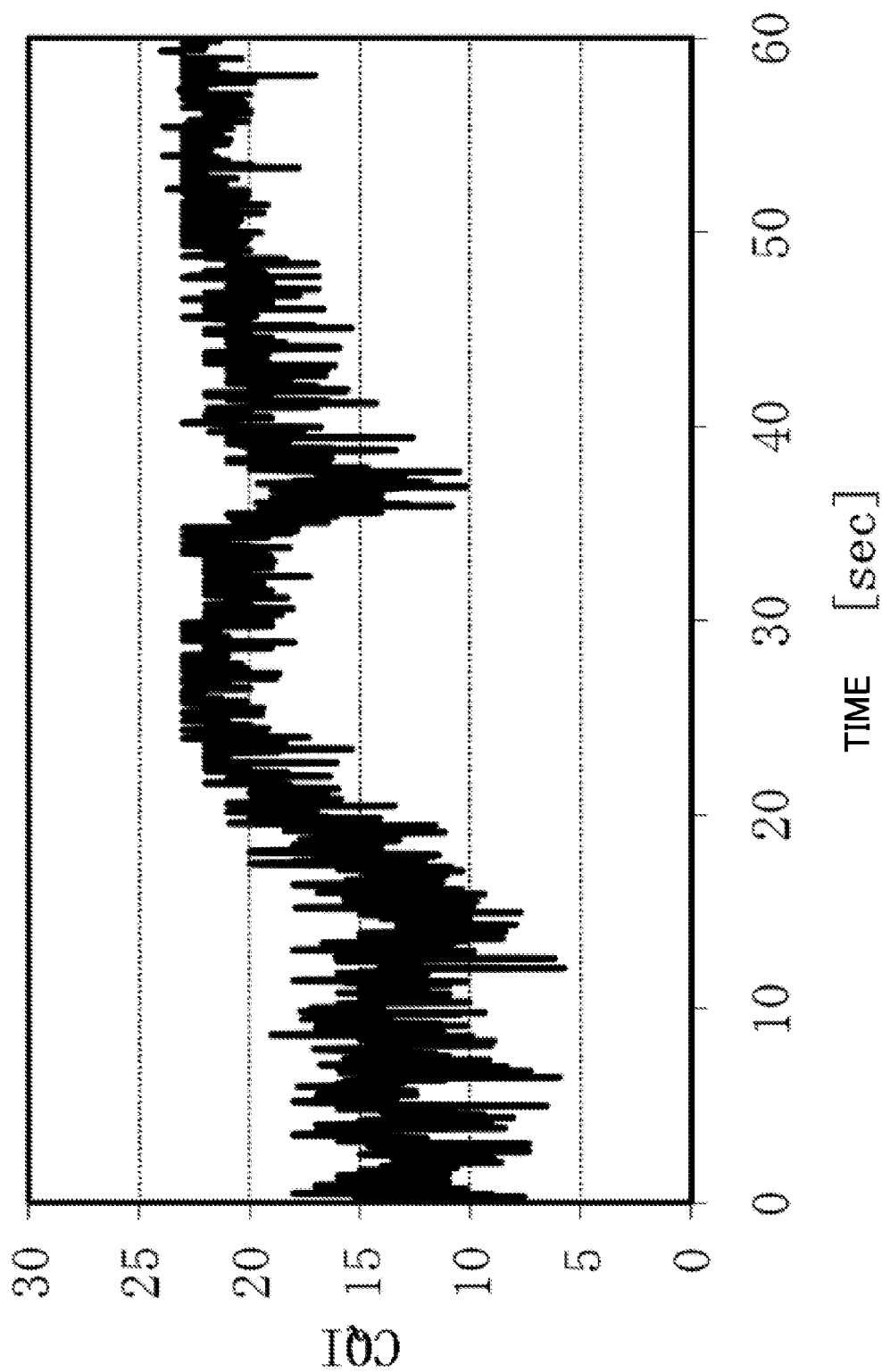


Fig.17

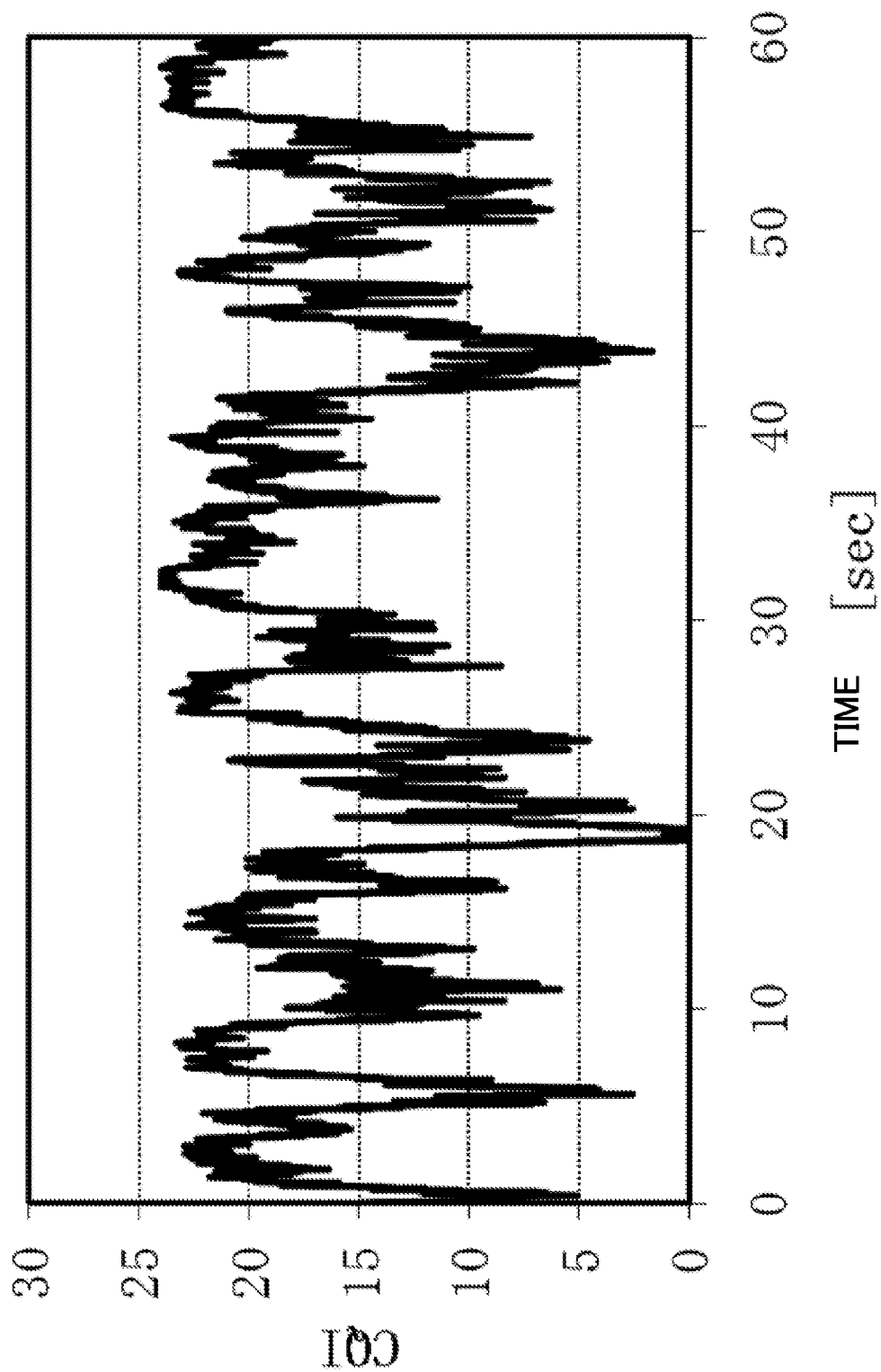


Fig.18

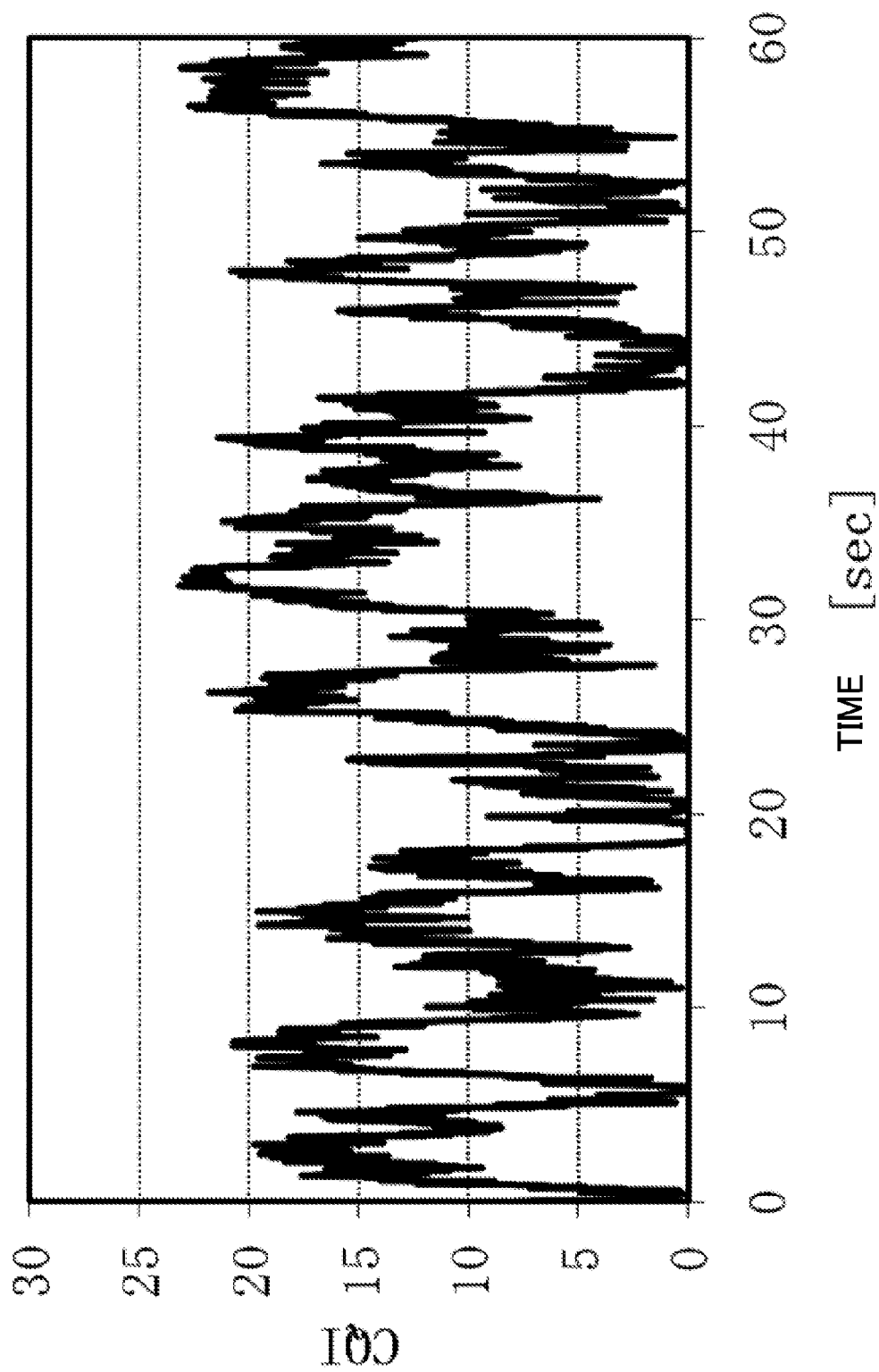


Fig.19

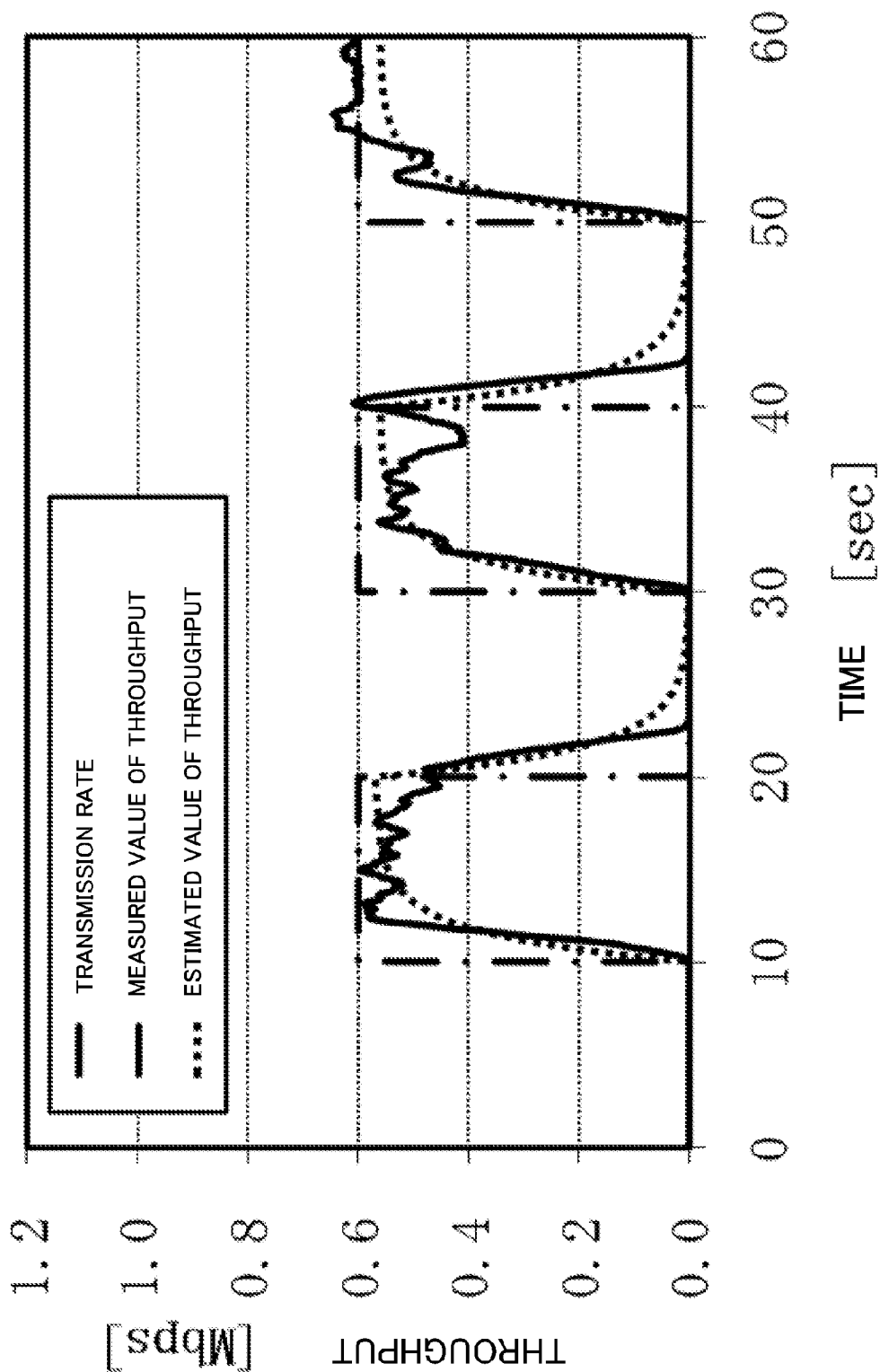


Fig.20

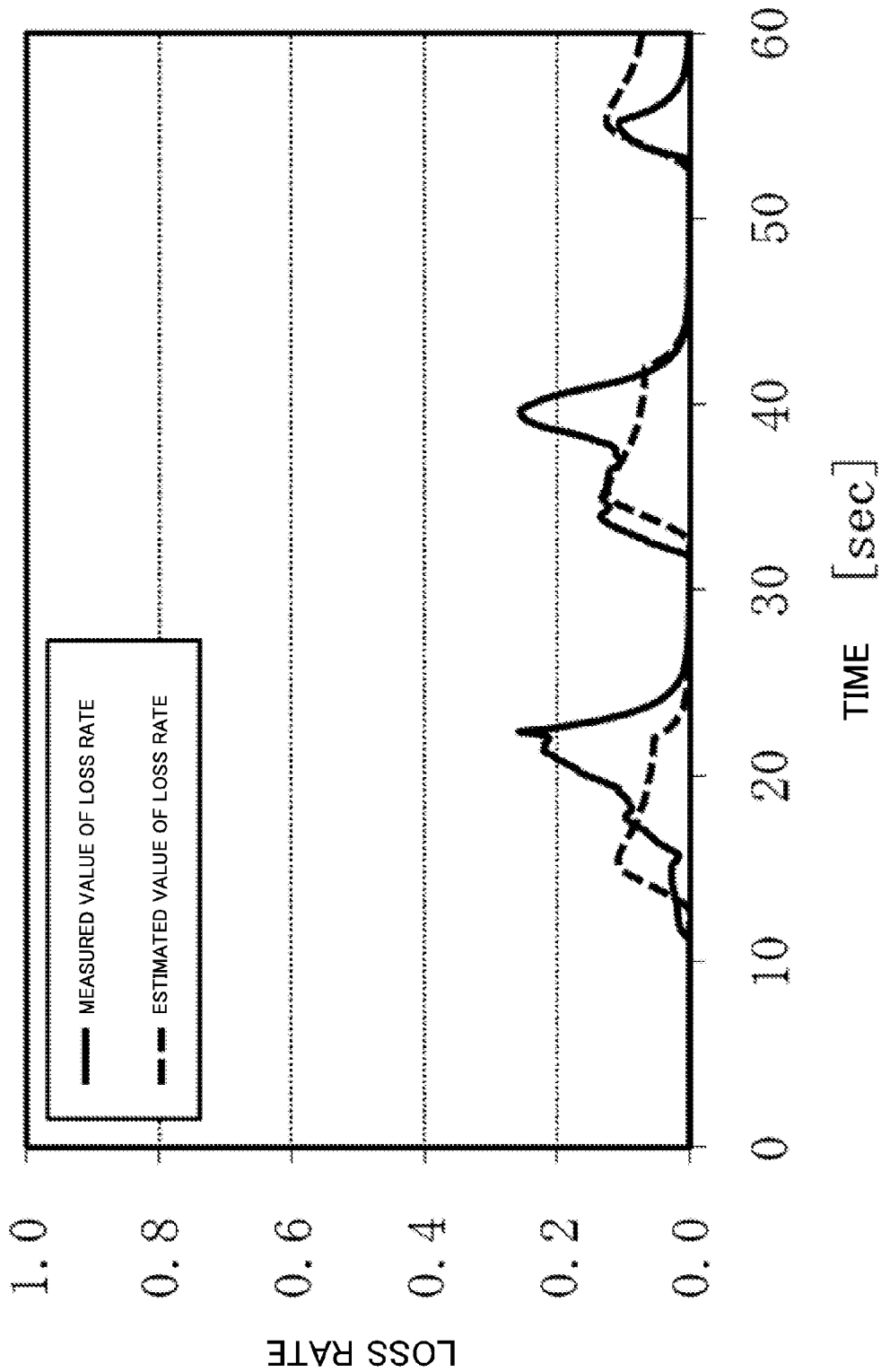


Fig.21

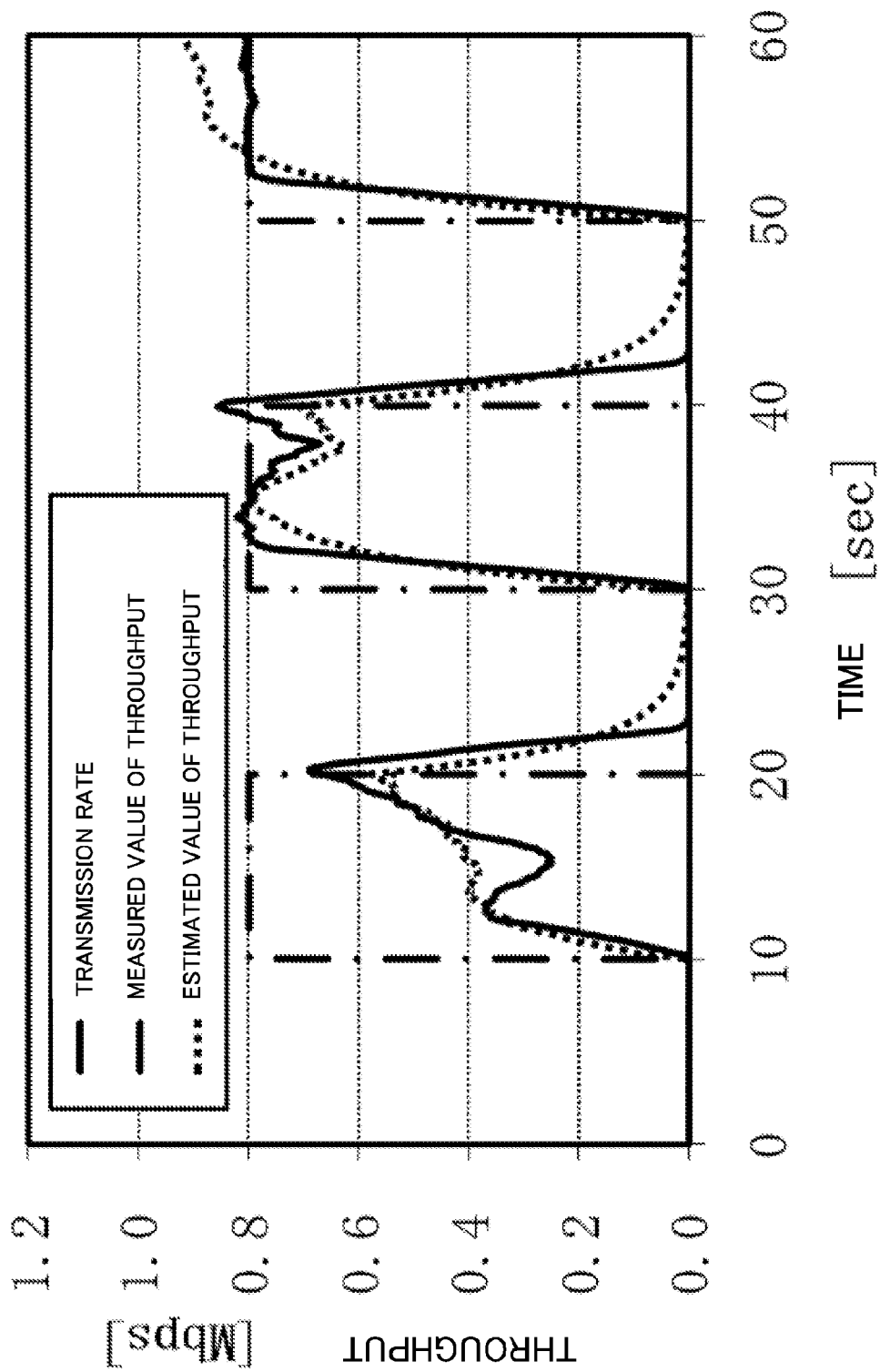


Fig.22

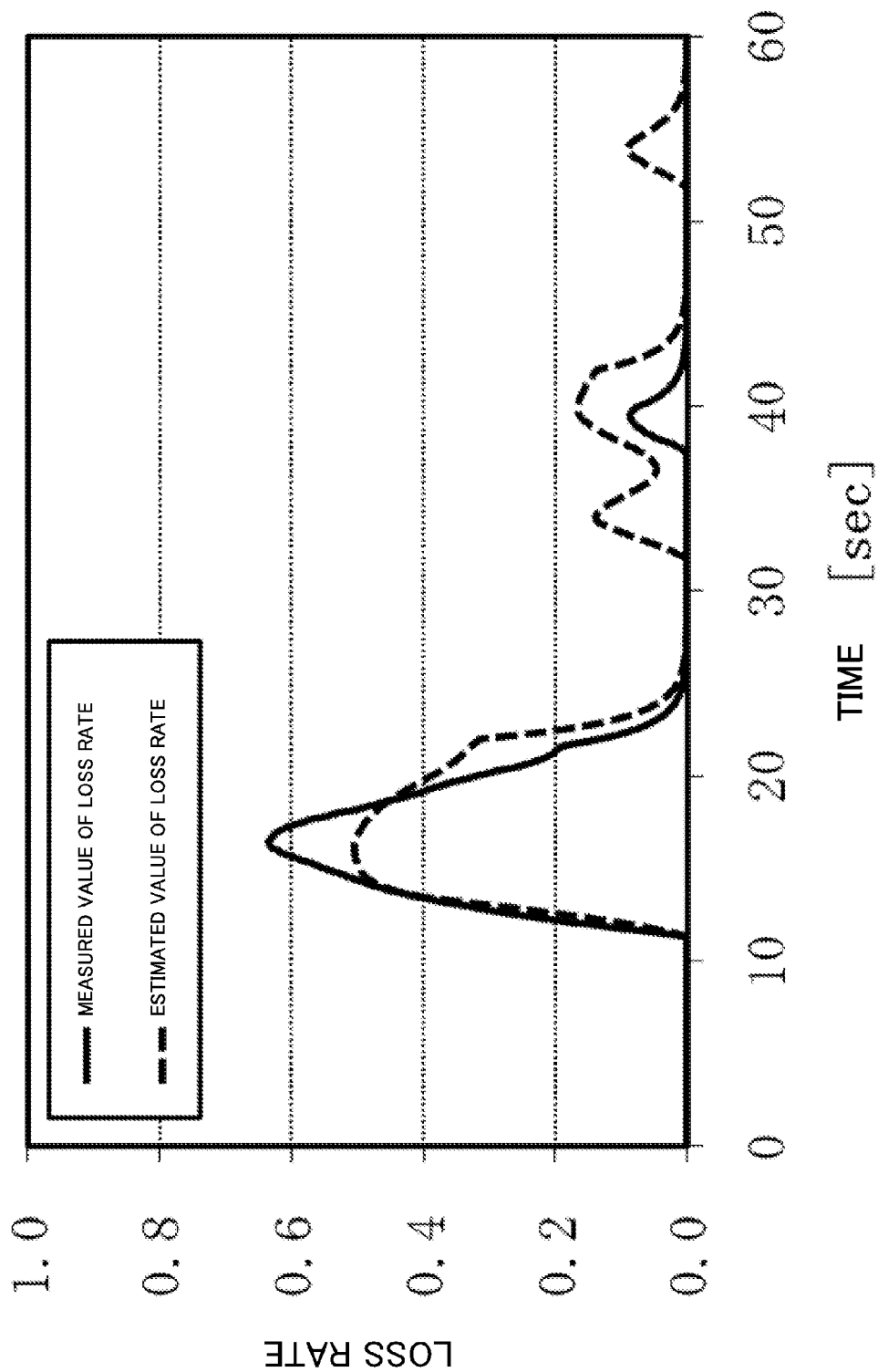


Fig.23

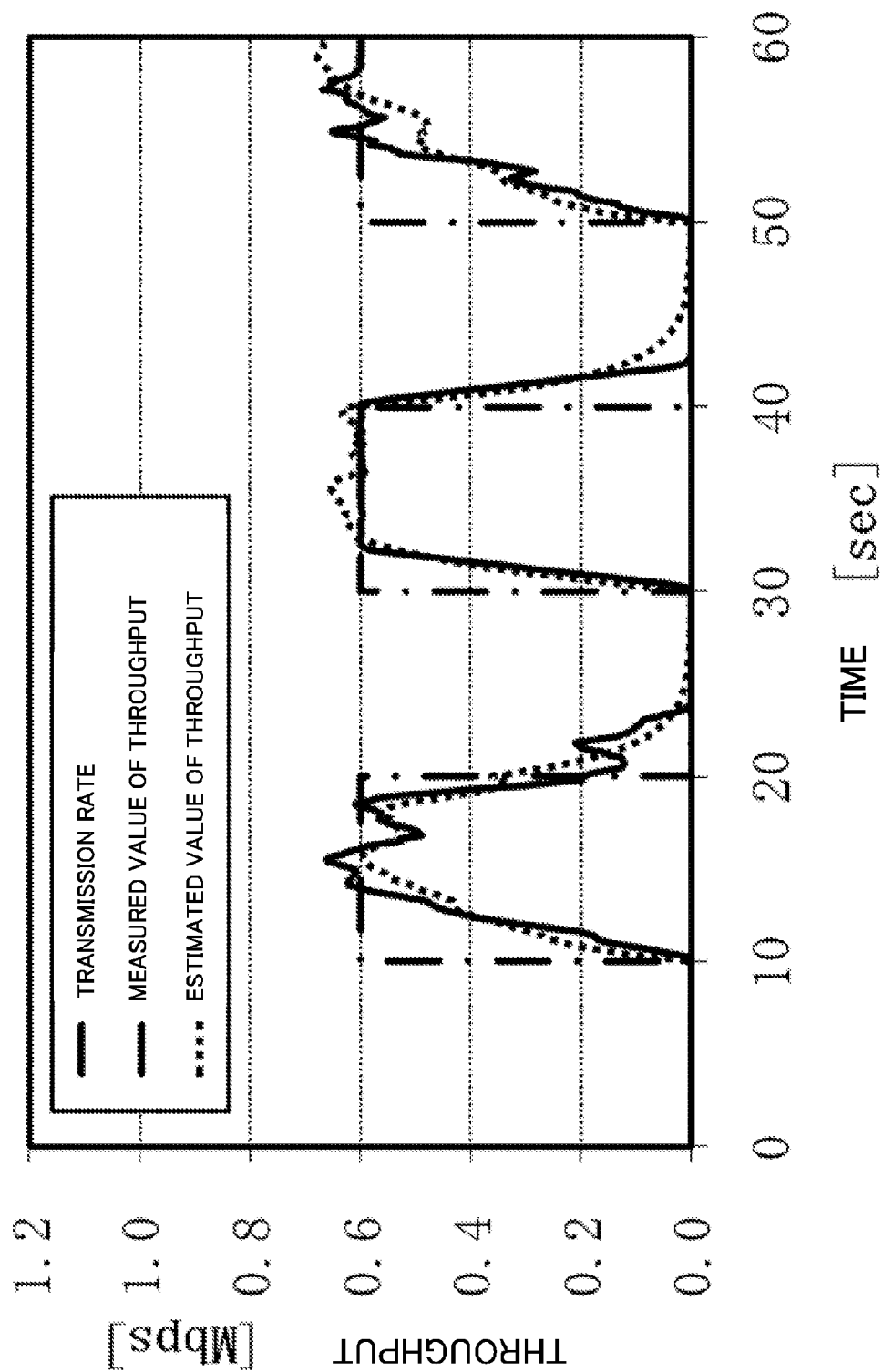


Fig.24

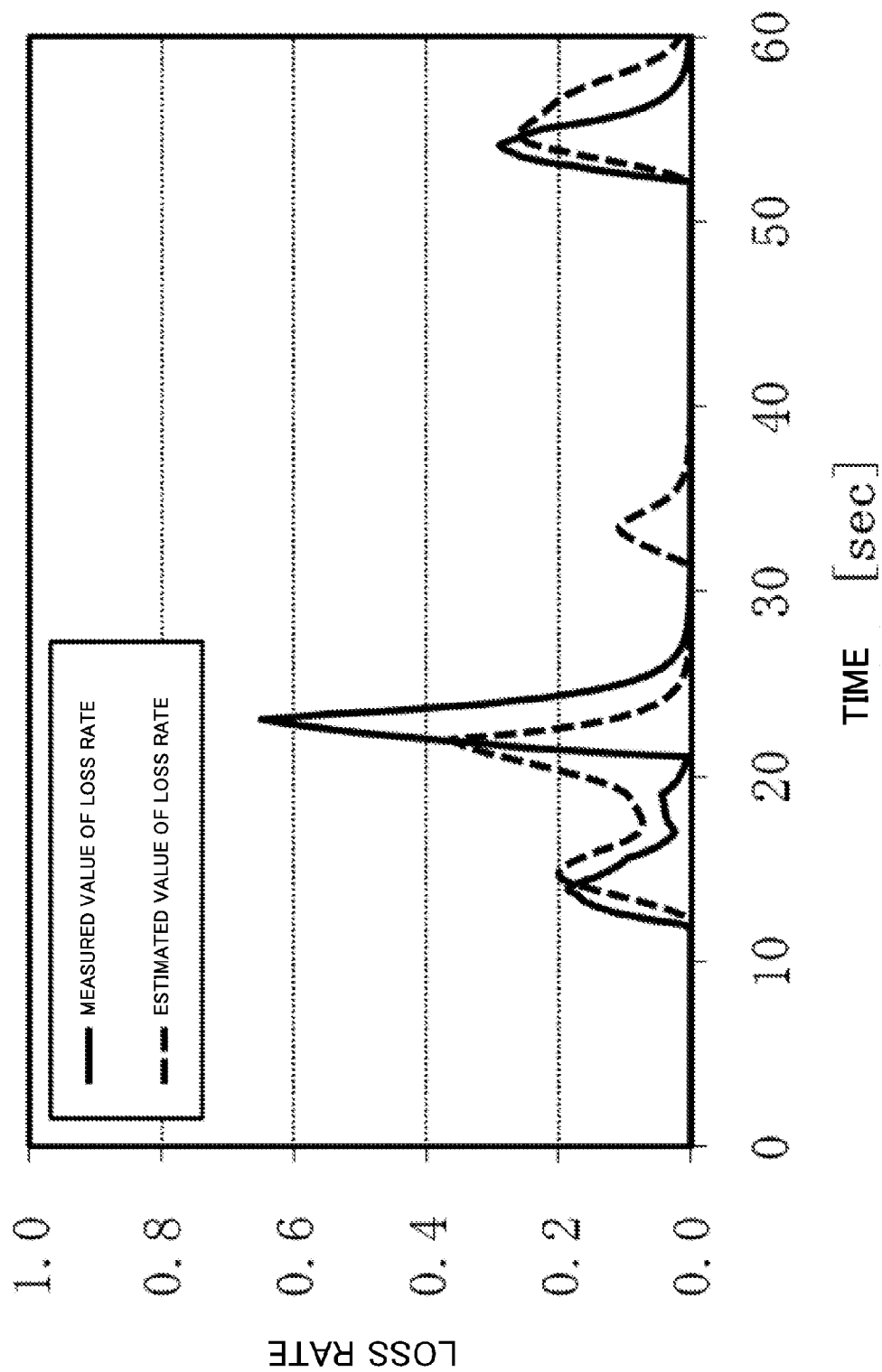


Fig.25

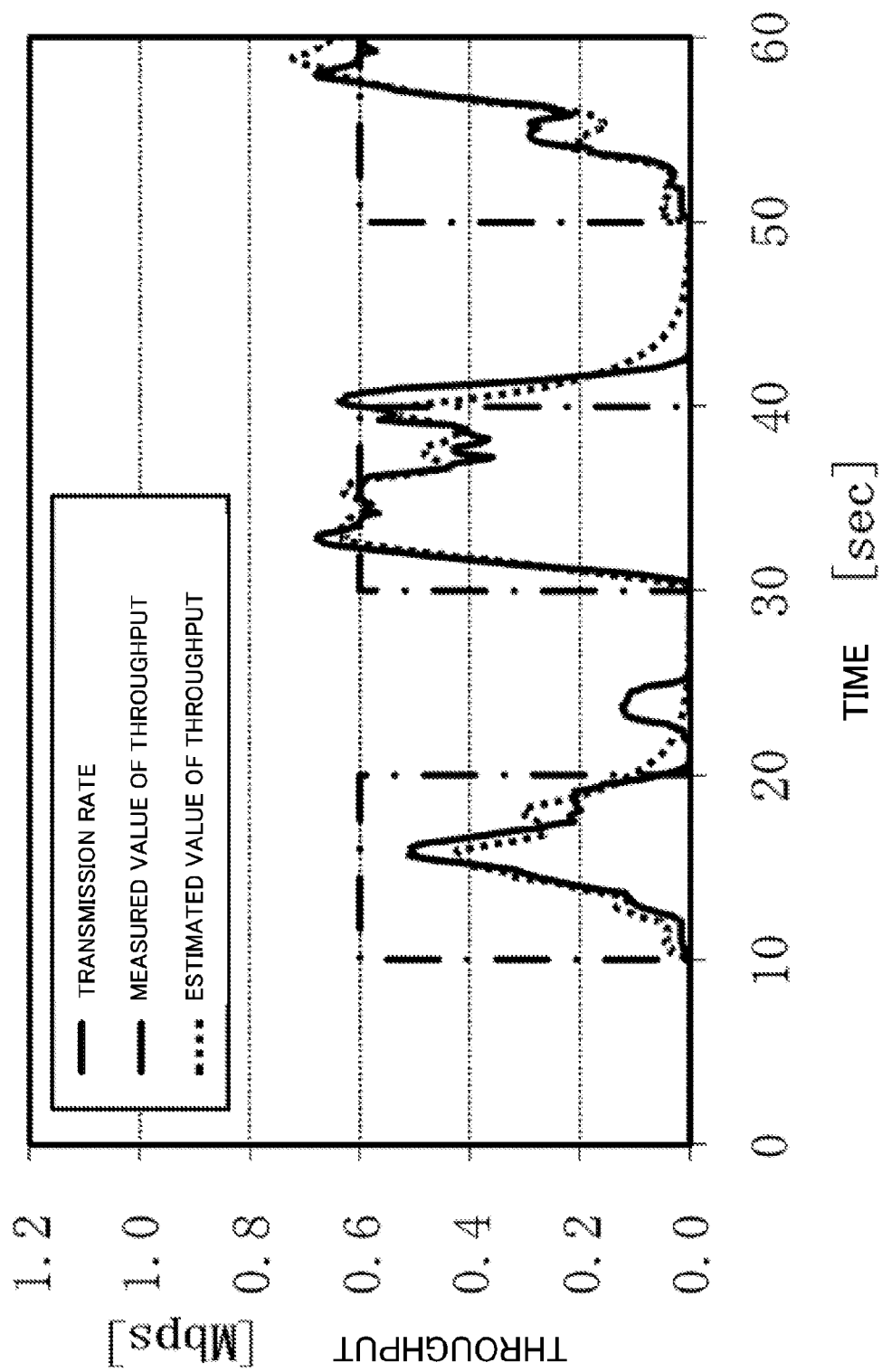


Fig.26

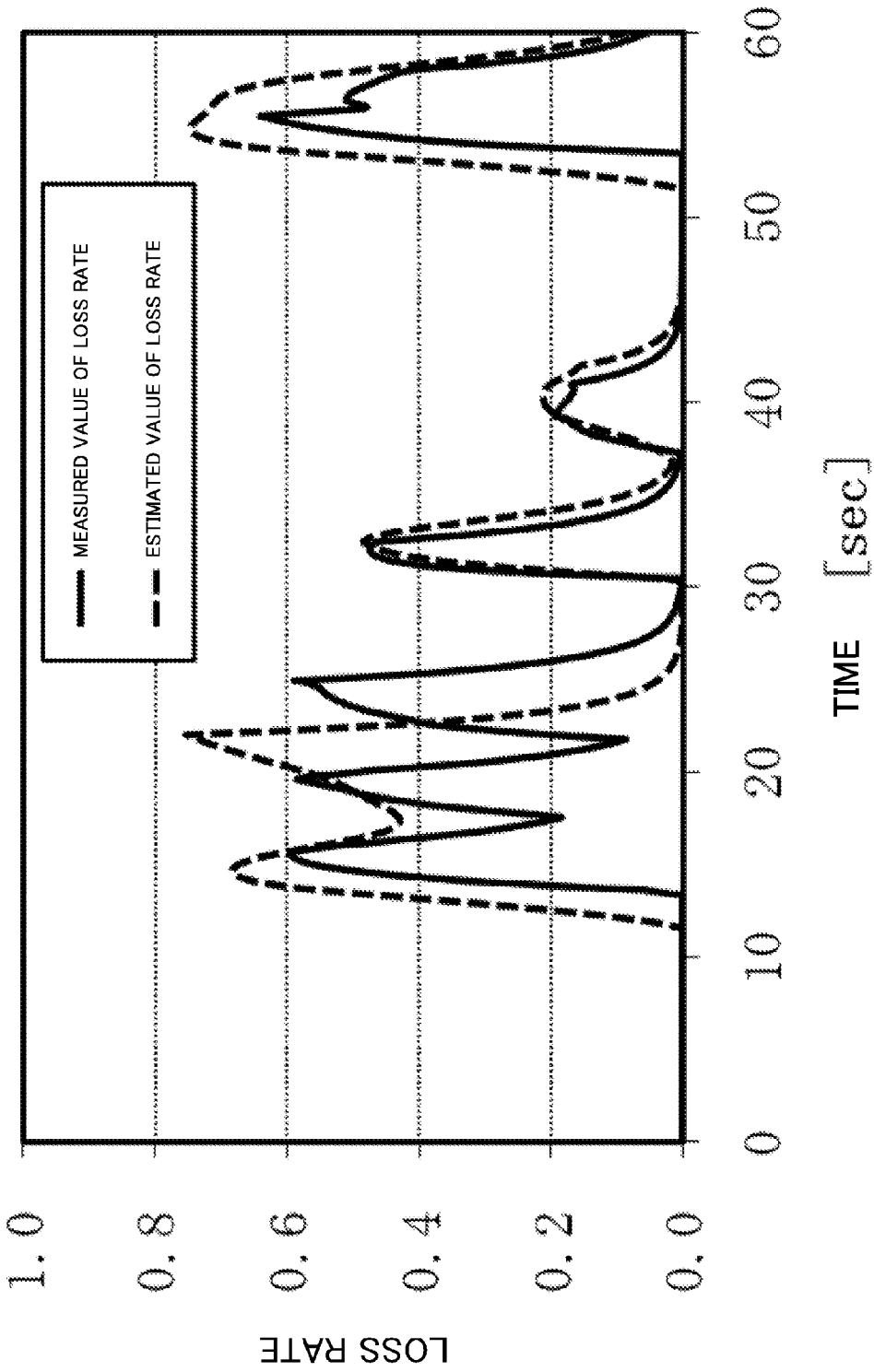
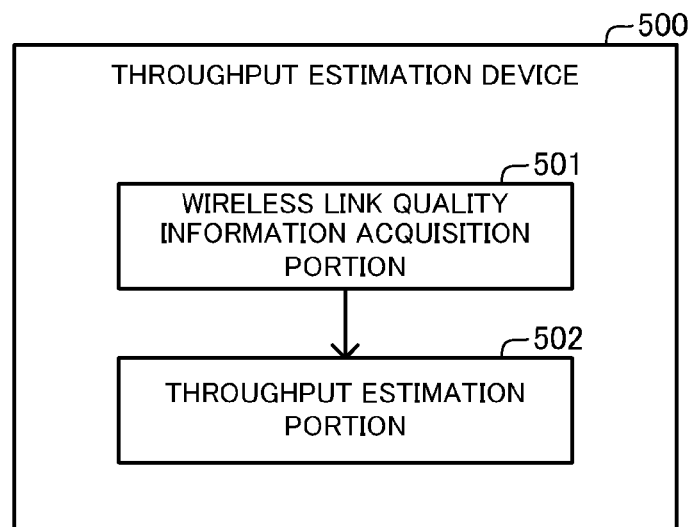


Fig.27



THROUGHPUT ESTIMATION DEVICE**CROSS REFERENCE TO RELATED APPLICATIONS**

This is a National Stage of International Application No. PCT/JP2011/006684 filed Nov. 30, 2011, claiming priority based on Japanese Patent Application No. 2011-016232 filed Jan. 28, 2011, the contents of all of which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

The present invention relates to throughput estimation devices estimating throughput.

BACKGROUND ART

When a transmitting device sends a data to a receiving device, there are cases that because some part of the data is lost (has disappeared), only the other part of the data arrives at the receiving device. Further, when the transmitting device sends a data to the receiving device, there are cases that because some part of the data is accumulated within the communication network, the arrival of the data at the receiving device is too late (the delay time, which is the time from the transmitting device sending the data to the data arriving at the receiving device, becomes too long).

Among the data sent by the transmitting device, the amount of the data (the data arrival amount) having arrived at (or being received by) the receiving device per unit time is called throughput.

For example, if the transmitting device sends a data to the receiving device at a transmission rate of 4 Mbps, then it is assumed that 25% of the data (that is, a part corresponding to 1 Mbps) is lost. Here, the transmission rate is the amount of the data sent by the transmitting device per unit time. In this case, the receiving device receives the data at 3 Mbps. That is, the throughput is 3 Mbps.

Further, even if no data is lost, it is still assumed that the receiving device receives the data at 3 Mbps because of the increase in delay time. In this case, the throughput is also 3 Mbps.

If the data sent from the transmitting device to the receiving device is multimedia data such as video and/or audio data, then any loss of the data may cause noise to occur in the video and/or audio. Further, an excessive delay time may possibly bring a stop to the play of the video and/or audio.

Therefore, it is considered as preferable to estimate the throughput with a high accuracy, and adjust the data size of the multimedia data sent by the transmitting device based on the estimated throughput. Hence, techniques for estimating the throughput are being developed. The throughput estimation devices disclosed in the following Patent Document 1 through Patent Document 6 are known as such kind of techniques.

Patent Document 1: Pamphlet of WO 08/143,026

Patent Document 2: JP 2004-254025 A

Patent Document 3: JP 2005-244851 A

Patent Document 4: JP 2007-116329 A

Patent Document 5: JP 2008-258877 A

Patent Document 6: JP 2008-278207 A

However, such a case can be assumed as to apply the above throughput estimation devices to a mobile communication system in which a mobile station (a receiving device) and a transmitting device are communicably connected via a wire-

less link established between the mobile station and a base station on a mobile communication network.

In this case, even for a constant transmission rate, the data transmission rate through the wireless link still changes with any change in the quality of the wireless link (the wireless link quality). As a result, the throughput also changes. Here, the data transmission rate is the amount of the data transmitted per unit time through the wireless link.

Referring to FIGS. 1A to 1C, the throughput change with the change in the wireless link quality will be explained in more detail.

The pipes in FIGS. 1A to 1C denote a wireless link. FIGS. 1A to 1C show that the thicker the pipe, the higher the data transmission rate through the wireless link (i.e. the higher the wireless link quality).

The arrows entering in the pipe denote the transmission rate. FIGS. 1A to 1C show that the more the number of the arrows entering in the pipe, the higher the transmission rate. Further, the arrows exiting from the pipe denote the throughput. FIGS. 1A to 1C show that the more the number of the arrows exiting from the pipe, the higher the throughput.

FIG. 1A shows that both the wireless link quality and the throughput are at the highest level. FIG. 1B shows that both the wireless link quality and the throughput are at the lowest level. FIG. 1C shows that both the wireless link quality and the throughput are at the second highest level. In this manner, the throughput also changes with the change in the wireless link quality.

However, the above throughput estimation devices estimate the throughput without being based on the wireless link quality. Therefore, it is liable to be unable to estimate the throughput with a high accuracy when the data is sent via the wireless link.

SUMMARY

Hence, an exemplary object of the present invention is to provide a throughput estimation device capable of solving the above problem of "being unable to estimate the throughput with a high accuracy when the data is sent via the wireless link".

In order to achieve this exemplary object, an aspect of the present invention provides a throughput estimation device including: a wireless link quality information acquisition means for acquiring wireless link quality information denoting a quality of a wireless link established between a mobile station and a base station on a mobile communication network; and a throughput estimation means for estimating a throughput which is the amount for the mobile station to receive per unit time a data sent by a transmitting device connected communicably with the mobile station via the wireless link, based on the acquired wireless link quality information.

Further, another aspect of the present invention provides a throughput estimation method including: acquiring wireless link quality information denoting a quality of a wireless link established between a mobile station and a base station on a mobile communication network; and estimating a throughput which is the amount for the mobile station to receive per unit time a data sent by a transmitting device connected communicably with the mobile station via the wireless link, based on the acquired wireless link quality information.

Further, still another aspect of the present invention provides a throughput estimation computer program including instructions for causing an information processing device to carry out a process including the steps of: acquiring wireless link quality information denoting a quality of a wireless link

established between a mobile station and a base station on a mobile communication network; and estimating a throughput which is the amount for the mobile station to receive per unit time a data sent by a transmitting device connected communicably with the mobile station via the wireless link, based on the acquired wireless link quality information.

Because the present invention is configured in the manner as described above, it is possible to estimate the throughput with a high accuracy when the data is sent via the wireless link.

BRIEF DESCRIPTION OF DRAWINGS

FIGS. 1A to 1C are explanatory diagrams conceptually showing a change in the throughput with a change in the wireless link quality;

FIG. 2 shows a schematic configuration of a mobile communication system in accordance with a first exemplary embodiment of the present invention;

FIG. 3 is a block diagram showing a schematic function of the mobile communication system in accordance with the first exemplary embodiment of the present invention;

FIG. 4 is a graph showing an example of the changes with time in transmission rate and throughput when a transmitting device sends data to a receiving device via a wireless link;

FIG. 5 is a graph showing the change with time in the value of wireless link quality;

FIG. 6 is a graph showing a correlation between the variation in the value of wireless link quality and the variation in throughput;

FIG. 7 is a graph showing an example of the respective changes with time in the estimated value of throughput, measured value of throughput, and smoothed CQI;

FIGS. 8A to 8C are explanatory diagrams conceptually showing an influence exerted by cross-traffic on the throughput;

FIG. 9 is an explanatory diagram conceptually showing a dynamic model in accordance with a second exemplary embodiment of the present invention;

FIG. 10 is an explanatory diagram conceptually showing a dynamic model in accordance with a modification of the second exemplary embodiment of the present invention;

FIG. 11 is an explanatory diagram conceptually showing a dynamic model in accordance with another modification of the second exemplary embodiment of the present invention;

FIG. 12 is a block diagram showing a schematic function of a mobile communication system in accordance with the second exemplary embodiment of the present invention;

FIG. 13 is an explanatory diagram conceptually showing the contents of simulations in accordance with the second exemplary embodiment of the present invention;

FIG. 14 is a graph showing a pattern of the transmission rate used in the simulations in accordance with the second exemplary embodiment of the present invention;

FIG. 15 is a graph showing a change with time in the value of wireless link quality in a first simulation in accordance with the second exemplary embodiment of the present invention;

FIG. 16 is a graph showing a change with time in the value of wireless link quality in a second simulation in accordance with the second exemplary embodiment of the present invention;

FIG. 17 is a graph showing a change with time in the value of wireless link quality in a third simulation in accordance with the second exemplary embodiment of the present invention;

FIG. 18 is a graph showing a change with time in the value of wireless link quality in a fourth simulation in accordance with the second exemplary embodiment of the present invention;

FIG. 19 is a graph showing the respective changes with time in the transmission rate, measured value of throughput, and estimated value of throughput in the first simulation in accordance with the second exemplary embodiment of the present invention;

FIG. 20 is a graph showing the respective changes with time in the measured value of loss rate and estimated value of loss rate in the first simulation in accordance with the second exemplary embodiment of the present invention;

FIG. 21 is a graph showing the respective changes with time in the transmission rate, measured value of throughput, and estimated value of throughput in the second simulation in accordance with the second exemplary embodiment of the present invention;

FIG. 22 is a graph showing the respective changes with time in the measured value of loss rate and estimated value of loss rate in the second simulation in accordance with the second exemplary embodiment of the present invention;

FIG. 23 is a graph showing the respective changes with time in the transmission rate, measured value of throughput, and estimated value of throughput in the third simulation in accordance with the second exemplary embodiment of the present invention;

FIG. 24 is a graph showing the respective changes with time in the measured value of loss rate and estimated value of loss rate in the third simulation in accordance with the second exemplary embodiment of the present invention;

FIG. 25 is a graph showing the respective changes with time in the transmission rate, measured value of throughput, and estimated value of throughput in the fourth simulation in accordance with the second exemplary embodiment of the present invention;

FIG. 26 is a graph showing the respective changes with time in the measured value of loss rate and estimated value of loss rate in the fourth simulation in accordance with the second exemplary embodiment of the present invention; and

FIG. 27 is a block diagram showing a schematic function of a throughput estimation device in accordance with a third exemplary embodiment of the present invention.

EXEMPLARY EMBODIMENTS

Hereinbelow, referring to FIGS. 1 through 27, explanations will be made with respect to each exemplary embodiment of a throughput estimation device, a throughput estimation method and a throughput estimation computer program in accordance with the present invention.

A First Exemplary Embodiment

Configuration

As shown in FIG. 2, a mobile communication system 1 in accordance with a first exemplary embodiment includes a transmitting device (throughput estimation device) 100, a receiving device (mobile station) 200, and a base station BS. The transmitting device 100 and the base station BS are connected communicably with each other via communication lines (communication lines constituting a mobile communication network in this example) NW.

The base station BS establishes a wireless link between itself and the receiving device 200. The wireless link constitutes the mobile communication network. The base station

BS carries out communications between itself and the receiving device **200** via the established wireless link.

The transmitting device **100** is an information processing device. The transmitting device **100** includes a central processing unit (CPU) and a storage device (memory and hard disk drive (HDD)) which are not shown. The transmitting device **100** is configured to realize an aftermentioned function by letting the CPU implement a program stored in the storage device.

The receiving device **200** is a mobile terminal. For example, the receiving device **200** is a cellphone terminal, smartphone, personal computer, PHS (Personal Handyphone System), PDA (Personal Data Assistance; Personal Digital Assistant), car navigation terminal, gaming terminal, or the like.

The receiving device **200** includes a CPU, a storage device (memory and HDD), input device (touch panel, button, keyboard, mouse, etc., for example), and output device (display, etc.) which are all not shown. The receiving device **200** is configured to realize an aftermentioned function by letting the CPU implement a program stored in the storage device.

(Function)

FIG. 3 is a block diagram showing a function of the mobile communication system **1**.

The function of the mobile communication system **1** includes a data transmission portion **101**, a reception rate acquisition portion (throughput acquisition means) **103**, a wireless link quality information acquisition portion (wireless link quality information acquisition means) **104**, a model parameter estimation portion (model parameter estimation means) **105**, and a throughput estimation portion (throughput estimation means) **106**.

Further, the function of the receiving device **200** includes a data reception portion **201**, a received information transmission portion **202**, a wireless link quality value acquisition portion **203**, and a wireless link quality value transmission portion **204**.

The data transmission portion **101** sends data to the receiving device **200**. In this example, the data transmission portion **101** sends data according to UDP (User Datagram Protocol)/IP (Internet Protocol), or TCP (Transmission Control Protocol)/IP.

The data reception portion **201** receives the data sent by the transmitting device **100**. The data reception portion **201** calculates (acquires) reception information each time a preset calculation period h passes over. The reception information includes information capable of calculating a reception rate which is the amount of the data received by the receiving device **200** per unit time from the transmitting device **100**.

The received information transmission portion **202** sends the reception information acquired by the data reception portion **201** to the transmitting device **100**.

The reception rate acquisition portion **103** receives the reception information sent by the received information transmission portion **202**. The reception rate acquisition portion **103** calculates (acquires) the reception rate (throughput) which is the amount of the data received by the receiving device **200** per unit time from the transmitting device **100**, based on the received reception information.

The wireless link quality value acquisition portion **203** acquires the value of wireless link quality which denotes the quality of the wireless link established between the base station BS and the receiving device **200** on the mobile communication network.

In this example, the value of wireless link quality is a channel quality indicator (CQI). Further, the value of wireless link quality may also be a signal to interference and noise

power ratio (SINR), signal to interference power ratio (SIR), signal to noise ratio (SNR), or the like.

The wireless link quality value transmission portion **204** sends the value of wireless link quality acquired by the wireless link quality value acquisition portion **203**, to the transmitting device **100**.

The wireless link quality information acquisition portion **104** receives the value of wireless link quality sent by the wireless link quality value transmission portion **204**. The wireless link quality information acquisition portion **104** carries out a smoothing process on the received value of wireless link quality, and acquires the smoothed value as wireless link quality information.

The wireless link quality information is information denoting the quality of the wireless link established between the base station BS and the receiving device **200** on the mobile communication network. In this example, the smoothing process is to take a moving average for the value of wireless link quality. That is, the wireless link quality information is the value of a moving average taken for the value of wireless link quality.

Further, the smoothing process may also be a process of calculating the value of averaging the value of wireless link quality acquired during each preset processing period. The wireless link quality information is the average value calculated for each processing period. Further, the smoothing process may also be a process of inputting the value of wireless link quality to a low-pass filter (LPF). In such case, the wireless link quality information is the value outputted from the low-pass filter.

Further, the wireless link quality information acquisition portion **104** may also be configured to acquire the received value of wireless link quality as the wireless link quality information.

The model parameter estimation portion **105** estimates model parameters based on the wireless link quality information acquired by the wireless link quality information acquisition portion **104**, the reception rate (throughput) acquired by the reception rate acquisition portion **103**, and an aftermentioned mathematical model. The model parameters are parameters for specifying the above mathematical model.

Hereinbelow, the mathematical model will be explained. The mathematical model denotes a relationship between the throughput and the wireless link quality information. The mathematical model is a model constructed by assuming equality between the throughput, and a polynomial function (a linear function or linear expression in this example) with the wireless link quality information as a variable. First, derivation of the mathematical model will be explained.

FIG. 4 is a graph showing an example of the changes with time in transmission rate and throughput when the transmitting device **100** sends data to the receiving device **200** via the wireless link. In this example, although the transmission rate is constant (a constant bit-rate (CBR)), the throughput is varying in a comparatively violent manner.

FIG. 5 is a graph showing the change with time in CQI as the value of wireless link quality in the above example. In this manner, the CQI is varying in a comparatively violent manner. Therefore, because the CQI (wireless link quality) varies in a comparatively violent manner, it is understood that the throughput also varies in a comparatively violent manner.

FIG. 6 is a graph showing a correlation between the variation in CQI and the variation in throughput. In FIG. 6, each triangle in solid lines denotes the throughput (measured value of throughput) and CQI (measured value of CQI) which are measured at an arbitrary point of time. By calculating a coefficient of correlation between the measured value of CQI and

the measured value of throughput, the resultant coefficient of correlation is 0.64. Therefore, it can be said that there is a kind of correlation between the measured value of CQI and the measured value of throughput.

However, the CQI is varying more violently than the throughput. Hence, investigation is also made on the relationship between the value of having smoothed the CQI (the smoothed CQI, i.e., the wireless link quality information), and the measured value of throughput. In FIG. 6, each circle in dotted lines denotes the measured value of throughput and the smoothed CQI at an arbitrary point of time.

Then, by calculating a coefficient of correlation between the smoothed CQI and the measured value of throughput, the resultant coefficient of correlation is 0.93. In this manner, it can be said that the correlation between the smoothed CQI and the measured value of throughput is closer (stronger) than the correlation between the measured value of CQI and the measured value of throughput.

Therefore, it can be said that there is a linear relation between the smoothed CQI and the measured value of throughput. That is, based on the mathematical model constructed by assuming equality between the throughput, and a linear function with the smoothed CQI as a variable, it is possible to denote the relation between the smoothed CQI and the throughput with a high accuracy.

This mathematical model is called CQI linear model. This mathematical model is expressed by the following Formula 1. Here, v is the throughput, q is the smoothed CQI (i.e., the wireless link quality information), a is the slope of the linear expression, and b is the intercept of the linear expression. a and b constitute the model parameters.

$$v=aq+b \quad [\text{Formula 1}]$$

In this example, the model parameter estimation portion **105** calculates (estimates) the model parameters by using the least-squares estimation method based on the smoothed CQI, measured value of throughput, and Formula 1.

The throughput estimation portion **106** estimates the throughput based on the mathematical model specified by the model parameters estimated by the model parameter estimation portion **105**, and the wireless link quality information acquired by the wireless link quality information acquisition portion **104**.

(Operation)

Next, an operation of the aforementioned mobile communication system **1** will be explained.

First, the transmitting device **100** sends a data to the receiving device **200**. With this, the receiving device **200** receives the data. Then, the receiving device **200** acquires reception information each time the aforementioned calculation period h passes over. Further, the receiving device **200** sends the acquired reception information to the transmitting device **100**.

With that, the transmitting device **100** receives the reception information. Then, the transmitting device **100** acquires the throughput based on the received reception information.

Further, the receiving device **200** acquires the value of wireless link quality. Then, the receiving device **200** sends the acquired value of wireless link quality to the transmitting device **100**. With this, the transmitting device **100** receives the value of wireless link quality. Then, the transmitting device **100** acquires the wireless link quality information based on the received value of wireless link quality.

Next, the transmitting device **100** estimates the model parameters based on the acquired throughput and the acquired wireless link quality information.

Thereafter, the receiving device **200** acquires the value of wireless link quality again. Then, the receiving device **200** sends the acquired value of wireless link quality to the transmitting device **100**. With this, the transmitting device **100** receives the value of wireless link quality. Then, the transmitting device **100** acquires the wireless link quality information based on the received value of wireless link quality.

Next, the transmitting device **100** estimates the throughput based on the mathematical model specified by the estimated model parameters, and the acquired wireless link quality information.

FIG. 7 is a graph showing an example of the respective changes with time in the throughput estimated by the transmitting device **100** (the estimated value of throughput), measured value of throughput, and smoothed CQI. In FIG. 7, the solid lines denote the measured value of throughput, the dotted lines denote the estimated value of throughput, and the chain lines denote the smoothed CQI.

In this manner, the transmitting device **100** can estimate the throughput with a high accuracy by using the CQI linear model.

As explained above, with the transmitting device (throughput estimation device) **100** in accordance with the first exemplary embodiment of the present invention, it is possible to estimate the throughput with a high accuracy when the data is sent via the wireless link.

A Second Exemplary Embodiment

Next, a mobile communication system in accordance with a second exemplary embodiment of the present invention will be explained. The mobile communication system in accordance with the second exemplary embodiment differs from the aforementioned mobile communication system in accordance with the first exemplary embodiment in the mathematical model used by the transmitting device. Therefore, the following explanation will be focused on this difference.

Now, on many occasions, cross-traffic is present in a communication network. Here, the cross-traffic is the other traffic than the traffic of attention (the self-traffic) among the traffics passing through an interval on the communication pathway. Here, the self-traffic is the data sent from the transmitting device **100** to the receiving device **200**.

Referring to FIGS. 8A to 8C, a detailed explanation will be made with respect to an influence exerted by the cross-traffic on the throughput.

The pipes in FIGS. 8A to 8C denote a communication bandwidth of an interval with the cross-traffic present in the communication pathway.

The arrows entering in the pipe denote the transmission rate. FIGS. 8A to 8C show that the more the number of the arrows entering in the pipe, the higher the transmission rate. Further, the arrows exiting from the pipe denote the throughput. FIGS. 8A to 8C show that the more the number of the arrows exiting from the pipe, the higher the throughput. Further, the arrows in solid lines denote the self-traffic, while the arrows in dotted lines denote the cross-traffic.

In the above interval, if the communication bandwidth used by the self-traffic increases (if the state shown in FIG. 8A changes to the state shown in FIG. 8B), then the data loss rate and delay time related to the cross-traffic also increase. Here, the data loss rate is the proportion of data (packet, for example) disappearing from a communication network. Further, the delay time is the time span from the point of sending a data to the point of receiving the data.

On the other hand, if the cross-traffic is sent according to TCP, then a transmission rate control is carried out to reduce

the data loss rate and delay time. That is, if the communication bandwidth used by the self-traffic increases, then the transmission rate for the cross-traffic is decreased. By virtue of this, the throughput of the self-traffic becomes even greater (to be the state shown in FIG. 8C).

In this manner, due to the interaction between the traffics, the throughput of the self-traffic undergoes a variation.

Hence, the transmitting device 100 in accordance with the second exemplary embodiment uses a mathematical model which has taken into consideration the influence from the interaction between the traffics on the throughput. This mathematical model denotes a relationship between the throughput, wireless link quality information, and transmission rate.

Here, referring to FIG. 9, the mathematical model in accordance with the second exemplary embodiment will be explained in detail.

As described above, it can be said that the qualitative relation between the cross-traffic flow and the throughput of the data sent from the transmitting device 100 to the receiving device 200 is a relation of mutually pushing away each other's flow (if one increases then the other is decreased, while if one decreases then the other is increased).

Hence, as shown in FIG. 9, the mathematical model is constructed by denoting the relation between the wireless link quality information, and the transmission rate and throughput for the self-traffic, based on a dynamic model (a viscoelastic body model) including a mobile body M1, a spring M2 as an elastic body (elastic element), and a dashpot M3 as a viscous body (viscous element).

This dynamic model simulates the data sent from the transmitting device 100 to the receiving device 200 by the fluid flowing through a passage defined by a first wall surface W1 and the mobile body M1. The mobile body M1 is a plate-like body which is arranged in the passage, and is movable in a preset moving direction (the vertical direction in FIG. 9).

The spring M2 is a coil spring with a spring constant (elastic coefficient) of K. The spring M2 has one end fixed to the mobile body M1 and the other end fixed to a second wall surface W2. By such configuration, the spring M2 deforms as much as the displacement of the mobile body M1 moving in the moving direction.

The dashpot M3 has a viscosity coefficient of D. The dashpot M3 has one end fixed to the mobile body M1 and the other end fixed to the second wall surface W2. By such configuration, the dashpot M3 delays the movement of the mobile body M1 in the moving direction due to some external force applied to the mobile body M1.

In this example, each of the spring constant K and the viscosity coefficient D is a constant value (has linear characteristics). Further, the spring constant K and/or the viscosity coefficient D may also have nonlinear characteristics.

The dynamic model assumes that by the fluid corresponding to the data sent at the transmission rate u (in bps) from the transmitting device 100 to the receiving device 200, the external force applied to the mobile body M1 in the moving direction is as great as $f(u)$ in accordance with the transmission rate u . Further, the dynamic model assumes that the throughput v (in bps) is the distance in the moving direction between a preset reference position p_{ref} (the position of the first wall surface W1 in this example) and the position p of the mobile body M1. That is, it can be said that this dynamic model denotes a relationship between the throughput and the transmission rate.

Further, in this dynamic model, when the mobile body M1 is positioned at a position p_0 (force-free position) away from the reference position p_{ref} by the distance v_0 (force-free distance) in the moving direction, the spring M2 generates no

elastic force (restoring force). Further, the elastic force generated by the spring M2 is as great as the value of the displacement $v-v_0$ of the mobile body M1 from the force-free position p_0 , multiplied by the elastic coefficient K which is a proportionality coefficient, and acts in the opposite direction to the direction in which the mobile body M1 has moved from the force-free position p_0 .

In addition, in this dynamic model, when the mobile body M1 stands still in the moving direction (the velocity is zero), the dashpot M3 generates no resisting force. Further, the resisting force generated by the dashpot M3 is as great as the value of the velocity of the mobile body M1 moving in the moving direction, multiplied by the viscosity coefficient D which is another proportionality coefficient, and acts in the opposite direction to the direction in which the mobile body M1 moves.

In this dynamic model, the equation governing the motion of the mobile body M1 is expressed as the following Formula 2. Further, the term dv/dt denotes the differential of the distance v with respect to time t in the moving direction between the reference position p_{ref} and the position p of the mobile body M1.

$$D \frac{dv}{dt} + K(v - v_0) = f(u) \quad [\text{Formula 2}]$$

The spring constant K in this viscoelastic body model can be considered as denoting the “unlikelihood of pushing away” the cross-traffic. Further, the viscosity coefficient D can be considered as denoting either the “viscous degree” or the “slowness of response” of the cross-traffic.

Further, other models may also be used as the dynamic model. For example, it is possible to adopt a model as the dynamic model which has also taken into consideration the inertia force of the mobile body M1. By the inertia force of the mobile body M1, it is possible to denote the change of overshooting of the transmission rate related to the cross-traffic. In this dynamic model, the equation governing the motion of the mobile body M1 is expressed as the following Formula 3. Further, M is the mass of the mobile body M1. Further, d^2v/dt^2 is the second order differential of the distance v with respect to time t in the moving direction between the reference position p_{ref} and the position p of the mobile body M1.

$$M \frac{d^2v}{dt^2} + D \frac{dv}{dt} + K(v - v_0) = f(u) \quad [\text{Formula 3}]$$

Further, the term “Kelvin-Voigt Model” is used to refer to the viscoelastic body model in which the spring M2 and dashpot M3 in parallel are connected to the mobile body M1 as described above. Further, as shown in FIG. 10, the dynamic model may also be a viscoelastic body model in which the spring M2 and dashpot M3 in series are connected to the mobile body M1. Such viscoelastic body model is called Maxwell Model.

Further, as shown in FIG. 11, the dynamic model may also be a viscoelastic body model (four element model) including a plurality of (two in this example) springs M2 and M4, and a plurality of (also two in this example) dashpots M3 and M5. In this example, the spring M2 and dashpot M3 in series are connected to the mobile body M1, and the spring M4 and dashpot M5 in parallel are connected to the dashpot M3.

Further, the equation governing the motion of the mobile body M1 in the dynamic model may also include a term

comprised of a third order differential of the distance v with respect to time t (a jerk or surge) in the moving direction between the reference position p_{ref} and the position p of the mobile body M1, or a term comprised of a fourth or higher order differential of the same.

Now, the CQI linear model (Formula 1), which is the mathematical model in accordance with the aforementioned first exemplary embodiment, has taken into consideration the influence exerted by the wireless link quality on the throughput. On the other hand, the above dynamic model (Formula 2) has taken into consideration the influence exerted by the cross-traffic on the throughput.

In an actual mobile communication network, both the wireless link quality and the cross-traffic exert influences on the throughput. Therefore, it is considered as preferable to use a mathematical model which has taken into consideration both the influence exerted by the wireless link quality on the throughput and the influence exerted by the cross-traffic on the throughput.

Hence, the transmitting device 100 in accordance with the second exemplary embodiment uses such a model as the mathematical model which mixes the CQI linear model and the dynamic model (to be called hybrid model, hereinafter).

Next, the hybrid model will be explained in detail.

The hybrid model defines the right-hand term $f(u)$ of Formula 2 denoting the dynamic model as in the following Formula 4.

$$f(u)=(aq+b)u \quad [\text{Formula 4}]$$

That is, the hybrid model is constructed by assuming that by the fluid corresponding to the data sent at the transmission rate u from the transmitting device 100 to the receiving device 200, the external force $f(u)$ applied to the mobile body M1 in the moving direction is as great as in accordance with both the transmission rate u and the wireless link quality information q .

To make a more specific description, the hybrid model is constructed by assuming that the above external force $f(u)$ is the product of the transmission rate u , and a polynomial function with the wireless link quality information q as a variable (a linear function or linear expression in this example).

However, in the mathematical models denoted by Formula 2 and Formula 4, among the four unknown constants D , K , a and b , independent constants are only three (one constant is subordinated to the other three constants). Therefore, it is possible to let $K=1$. That is, the hybrid model is expressed as the following Formula 5. Here, let $v_0=0$.

$$D \frac{dv}{dt} + v = (aq + b)u \quad [\text{Formula 5}]$$

In this manner, it can be said that the hybrid model is expressed by an ordinary differential equation for the throughput v , having an inhomogeneous term of a function with the transmission rate u and the wireless link quality information q as respective variables. Here, the inhomogeneous term is the product of the transmission rate u , and a polynomial function with the wireless link quality information q as a variable (a linear function or linear expression in this example). Further, it can also be said that the hybrid model is constructed to let the inhomogeneous term express the external force $f(u)$.

Here, if both sides of Formula 5 are divided by $(aq+b)$, then the hybrid model is expressed also as Formula 6.

$$\frac{D}{aq+b} \frac{dv}{dt} + \frac{1}{aq+b} v = u \quad [\text{Formula 6}]$$

Formula 6 uses $(D/(aq+b))$ instead of D and $(1/(aq+b))$ instead of K , D and K being used in Formula 2, and lets $f(u)=u$. That is, it is also conceivable that the hybrid model is expressed by a function taking, as its variable, the wireless link quality information of each of the viscosity coefficient and elastic coefficient in the dynamic mode.

Hereinabove, the hybrid model, which is the mathematical model in accordance with the second exemplary embodiment, has been explained.

Next, a method will be explained for estimating D , a , and b which are the model parameters for specifying the hybrid model.

The method for estimating the model parameters D , a , and b may be either a method of analytically calculating the optimum solution such as the least-squares estimation method, or a method of estimating the model parameters by repetitive calculation such as the steepest descent method.

Hereinbelow, an example will be explained with respect to the method of estimating the model parameters D , a , and b by the least-squares estimation method.

First, Formula 5, which is expressed by a differential equation with respect to a continuous time, is rewritten to a difference equation. In this example, as shown in the following Formula 7, the calculation period (sampling interval) h is taken as a time interval (time step), and backward difference is used.

$$\frac{D}{2h} \{3v(k) - 4v(k-1) + v(k-2)\} + v(k) = \{aq(k) + b\}u(k) \quad [\text{Formula 7}]$$

Here, solving Formula 7 for $v(k)$ obtains Formula 8.

$$v(k) = \frac{D}{3D+2h} \{4v(k-1) - v(k-2)\} + \frac{2ha}{3D+2h} q(k)u(k) + \frac{2hb}{3D+2h} u(k) \quad [\text{Formula 8}]$$

From Formula 8, $\phi(k)$ and θ are defined as by Formula 9 and Formula 10, respectively. Here, " X^T " denotes the transposed matrix of a matrix X . Further, $\phi(k)$ and θ are three-dimensional column vectors, respectively.

$$\phi(k) = [4v(k-1) - v(k-2), q(k)u(k), u(k)]^T \quad [\text{Formula 9}]$$

$$\theta = \frac{1}{3D+2h} [D, 2ha, 2hb]^T \quad [\text{Formula 10}]$$

Formula 8, which is a difference equation, can be expressed as shown in Formula 11 by using $\phi(k)$ and θ .

$$v(k) = \phi(k)^T \theta \quad [\text{Formula 11}]$$

According to Formula 11, it is possible to apply the least-squares estimation method to θ . By letting the θ estimated by the least-squares estimation method be θ_e , it is possible to find θ_e by the following Formula 12. Here, $\Sigma(x)$ denotes the value of summing X for k (that is, the summation of X for every calculation period h). Further, X^{-1} denotes the inverse matrix of the matrix X .

$$\theta_e = [\Sigma\{\phi(k)\phi(k)^T\}]^{-1} [\Sigma\{\phi(k)v(k)\}] \quad [\text{Formula 12}]$$

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Then, by letting the estimated θ_e be $\theta_e=[\theta_1, \theta_2, \theta_3]$, the model parameters D, a, and b can be found by Formula 13, Formula 14, and Formula 15, respectively.

$$D = \frac{2h\theta_1}{1-3\theta_1} \quad [\text{Formula 13}]$$

$$a = \frac{\theta_2}{1-3\theta_1} \quad [\text{Formula 14}]$$

$$b = \frac{\theta_3}{1-3\theta_1} \quad [\text{Formula 15}]$$

Further, as shown in FIG. 12, the function of the transmitting device 100 in accordance with the second exemplary embodiment includes a transmission rate acquisition portion (transmission rate acquisition means) 102, in addition to the function of the transmitting device 100 in accordance with the first exemplary embodiment.

Each time the calculation period h passes over, the transmission rate acquisition portion 102 calculates (acquires) the transmission rate which is the amount (size) of the data sent by the data transmission portion 101 to the receiving device 200 per unit time.

Then, the model parameter estimation portion 105 in accordance with the second exemplary embodiment calculates (estimates) the model parameters by using the least-squares estimation method as described before, based on the wireless link quality information (the smoothed CQI in this example) $q(k)$ acquired by the wireless link quality information acquisition portion 104, the throughput (the estimated value of throughput) $v(k)$ acquired by the reception rate acquisition portion 103, the transmission rate $u(k)$ acquired by the transmission rate acquisition portion 102, and the aforementioned hybrid model.

Further, the throughput estimation portion 106 in accordance with the second exemplary embodiment estimates the throughput based on the mathematical model (hybrid model) specified by the model parameters estimated by the model parameter estimation portion 105, the wireless link quality information acquired by the wireless link quality information acquisition portion 104, and the transmission rate acquired by the transmission rate acquisition portion 102. In this example, the throughput estimation portion 106 estimates the throughput based on Formula 8.

As explained hereinabove, according to the transmitting device (throughput estimation device) 100 in accordance with the second exemplary embodiment of the present invention, it is possible to realize a similar function and effect to that of the transmitting device 100 in accordance with the first exemplary embodiment.

Further, the transmitting device 100 in accordance with the second exemplary embodiment estimates the throughput based on the mathematical model constructed by denoting the relation between the transmission rate and the throughput based on a dynamic model. By virtue of this, it is possible to estimate the throughput with an even higher accuracy when cross-traffic is present.

In addition, the transmitting device 100 in accordance with the second exemplary embodiment estimates the throughput based on the mathematical model constructed by denoting the relation between the transmission rate and the throughput based on a dynamic model including an elastic body and a viscous body.

Now, the elastic force of the elastic body denotes better the change of the transmission rate related to the cross-traffic,

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arising from the change of the transmission rate related to the self-traffic. Further, delay time is necessary from the transmitting device 100 changing the transmission rate related to the self-traffic to changing the transmission rate related to the cross-traffic. The resisting force of the viscous body denotes this delay time better. Therefore, according to the transmitting device 100 in accordance with the second exemplary embodiment, it is possible to estimate the throughput with an even higher accuracy when cross-traffic is present.

Next, the effect of the transmitting device 100 in accordance with the second exemplary embodiment will be explained more specifically through the results of the following simulations.

FIG. 13 is an explanatory diagram conceptually showing the contents of the simulations. In the simulations, a plurality of (in this example, 12) users R1 to R4 and C1 to C8 each hold one of mutually different receiving devices 200.

Each of the users R1 to R4 holds the receiving device 200 as the object of estimating the throughput. The user R1 is walking at a position 100 m away from the base station BS. The user R2 is walking at a position 300 m away from the base station BS. The user R3 rides in a car running at a position 300 m away from the base station BS. The user R4 rides in a car running at a position 500 m away from the base station BS.

Further, each of the users C1 to C8 holds the receiving device 200 receiving the cross-traffic. The user C1 is positioned in a building 100 m away from the base station BS. The user C2 is positioned in a building 300 m away from the base station BS. The user C3 is positioned in a building 500 m away from the base station BS.

The user C4 is walking at a position 700 m away from the base station BS. The user C5 rides in a car running at a position 700 m away from the base station BS. The user C6 rides in a car running at another position 700 m away from the base station BS. The user C7 is walking at a position 1000 m away from the base station BS. The user C8 is positioned in a building 1000 m away from the base station BS.

In this case, the longer the distance between the receiving device 200 and the base station BS, the worse (the lower) the wireless link quality. Further, the users who ride in moving cars have a lower wireless link quality than the users who are walking.

Further, in the simulations, the transmitting device 100 sent a data at a transmission rate with a preset pattern to each of the receiving devices 200 held by the users R1 to R4 via the base station BS.

As shown in FIG. 14, the pattern is a rectangular wave which alternately repeats 0 Mbps and 0.6 Mbps for every ten minutes (0.8 Mbps only for the transmission to the receiving device 200 held by the user R2).

Further, the cross-traffic is sent according to FTP (File Transfer Protocol)/TCP. In this example, the cross-traffic is a traffic involving file download.

This time, four simulations were carried out.

In the first simulation, the receiving device 200 held by the user R1 is the object of estimating the throughput, and the cross-traffic is sent only to each of the receiving devices 200 held by the users C1 to C5.

In the second simulation, the receiving device 200 held by the user R2 is the object of estimating the throughput, and the cross-traffic is sent only to each of the receiving devices 200 held by the users C1 to C3.

In the third simulation, the receiving device 200 held by the user R3 is the object of estimating the throughput, and the cross-traffic is sent only to each of the receiving devices 200 held by the users C1 to C3.

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In the fourth simulation, the receiving device **200** held by the user **R4** is the object of estimating the throughput, and the cross-traffic is sent only to each of the receiving devices **200** held by the users **C1** to **C3**.

Then, for each of the four simulations, the transmitting device **100** estimates the model parameters based on the acquired throughput (the estimated value of throughput), the acquired wireless link quality information (the smoothed CQI), and the mathematical model (hybrid model).

Further, for each of the four simulations, the transmitting device **100** estimates the throughput based on the mathematical model (hybrid model) specified by the estimated model parameters, the transmission rate, and the acquired wireless link quality information (the smoothed CQI).

FIG. **15** is a graph showing a change with time in the value of wireless link quality (CQI in this example) denoting the quality of the wireless link established between the base station BS and the receiving device **200** held by the user **R1**. The CQI for the receiving device **200** held by the user **R1** is very high, and varies very little with time (being very stable).

FIG. **16** is a graph showing a change with time in the value of wireless link quality denoting the quality of the wireless link established between the base station BS and the receiving device **200** held by the user **R2**. The CQI for the receiving device **200** held by the user **R2** is comparatively high, and varies comparatively little with time (being comparatively stable).

FIG. **17** is a graph showing a change with time in the value of wireless link quality denoting the quality of the wireless link established between the base station BS and the receiving device **200** held by the user **R3**. The CQI for the receiving device **200** held by the user **R3** varies very greatly with time (being unstable), and its average value is about the same as that of the receiving device **200** held by the user **R2**.

FIG. **18** is a graph showing a change with time in the value of wireless link quality denoting the quality of the wireless link established between the base station BS and the receiving device **200** held by the user **R4**. The CQI for the receiving device **200** held by the user **R4** is very low, and varies very greatly with time (being unstable). That is, it can be said that this wireless link is very unstable.

FIG. **19** is a graph showing the respective changes with time in the transmission rate, measured value of throughput, and estimated value of throughput (the throughput estimated by the transmitting device **100**), in the first simulation. As shown in FIG. **15**, because the value of wireless link quality is stable at a high value, the throughput is mainly under the influence of cross-traffic.

If the transmission rate is increased in a step-like manner (i.e., discontinuously), then with respect to the change of the transmission rate, the change of the throughput delays as long as the time required to push away the cross-traffic. That is, as shown in FIG. **19**, the initial rise of the throughput draws a curve. The estimated value of the throughput is successfully reflecting this curve drawn by the measured value of the throughput.

Further, if the transmission rate is increased in a step-like manner, then even after the delay time is over, it is still impossible to push away all cross-traffic. That is, as shown in FIG. **19**, the maximum value of the throughput is less than the maximum value of the transmission rate. The estimated value of the throughput is successfully reflecting that the maximum measured value of the throughput is less than the maximum value of the transmission rate.

In this manner, the transmitting device **100** can estimate the throughput with a high accuracy by using the hybrid model.

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FIG. **20** is a graph showing the respective changes with time in the measured value of loss rate (packet loss rate) and estimated value of loss rate (the loss rate calculated based on the throughput estimated by the transmitting device **100**), in the first simulation. In this manner, the transmitting device **100** can also estimate the loss rate with a high accuracy by using the hybrid model.

FIG. **21** is a graph showing the respective changes with time in the transmission rate, measured value of throughput, and estimated value of throughput in the second simulation. As shown in FIG. **16**, because the value of wireless link quality varies to some extent, the throughput is also under a comparatively great influence of the wireless link quality in addition to the cross-traffic.

The influence exerted by the wireless link quality on the throughput is seen to be strong especially in the period of 10 to 20 seconds. During the period of 10 to 20 seconds, because the value of wireless link quality is comparatively low, the throughput is also comparatively low. On the other hand, during the period after 30 seconds, because the value of wireless link quality is stable at a comparatively high value, the throughput changes in the same manner as in the first simulation.

In this manner, in the second simulation, the throughput is under a comparatively great influence of both the wireless link quality and the cross-traffic. As shown in FIG. **21**, in such case, too, the transmitting device **100** can still estimate the throughput with a high accuracy by using the hybrid model.

FIG. **22** is a graph showing the respective changes with time in the measured value of loss rate and estimated value of loss rate in the second simulation. In this manner, the transmitting device **100** can estimate the loss rate with a high accuracy by using the hybrid model, including the rapid increase in loss rate during the period of 10 to 20 seconds.

FIG. **23** is a graph showing the respective changes with time in the transmission rate, measured value of throughput, and estimated value of throughput in the third simulation. As shown in FIG. **17**, because the value of wireless link quality varies very greatly, the throughput is under a comparatively great influence of the wireless link quality.

During the period of 10 to 20 seconds, and during the period of 50 to 60 seconds, there is a time when the wireless link quality decreases comparatively greatly. Due to this influence, there is a time when the throughput also decreases comparatively greatly. On the other hand, during the period of 30 to 40 seconds, because the wireless link quality is comparatively high, the throughput is mainly under the influence of the cross-traffic.

Thus, in the third simulation, the throughput is also under a comparatively great influence of both the wireless link quality and the cross-traffic. As shown in FIG. **23**, in such case, too, the transmitting device **100** can still estimate the throughput with a high accuracy by using the hybrid model.

FIG. **24** is a graph showing the respective changes with time in the measured value of loss rate and estimated value of loss rate in the third simulation. In this manner, the transmitting device **100** can estimate the loss rate with a high accuracy by using the hybrid model, including the packet loss occurring when the wireless link quality decreases greatly.

FIG. **25** is a graph showing the respective changes with time in the transmission rate, measured value of throughput, and estimated value of throughput in the fourth simulation. As shown in FIG. **18**, because the value of wireless link quality varies very greatly, the throughput is under a comparatively great influence of the wireless link quality.

During the period when the wireless link quality is low, the throughput is also low. Thus, in the fourth simulation, the

throughput is also under a comparatively great influence of both the wireless link quality and the cross-traffic. As shown in FIG. 25, in such case, too, the transmitting device 100 can still estimate the throughput with a high accuracy by using the hybrid model.

FIG. 26 is a graph showing the respective changes with time in the measured value of loss rate and estimated value of loss rate in the fourth simulation. In this manner, the transmitting device 100 can estimate the loss rate with a high accuracy by using the hybrid model, including the packet loss occurring when the wireless link quality decreases greatly.

In the above manner, from the simulation results, too, it becomes obvious that the transmitting device 100 in accordance with the second exemplary embodiment can estimate the throughput with a high accuracy when a data is sent via the wireless link when cross-traffic is present.

Further, while the mathematical model in the second exemplary embodiment is constructed by expressing the relationship between the throughput, the wireless link quality information, and the transmission rate based on a dynamic model, it may also be constructed by expressing this relationship based on another model (such as a thermal conduction model, fluid model, circuit model, or the like).

A Third Exemplary Embodiment

Next, referring to FIG. 27, a throughput estimation device in accordance with a third exemplary embodiment of the present invention will be explained.

A throughput estimation device 500 in accordance with the third exemplary embodiment includes a wireless link quality information acquisition portion (wireless link quality information acquisition means) 501 acquiring wireless link quality information denoting a quality of a wireless link established between a mobile station and a base station on a mobile communication network, and a throughput estimation portion (throughput estimation means) 502 estimating a throughput which is the amount for the mobile station to receive per unit time a data sent by a transmitting device connected communicably with the mobile station via the wireless link, based on the acquired wireless link quality information.

According to the third exemplary embodiment, it is possible to estimate the throughput with a high accuracy when a data is sent via the wireless link.

Hereinabove, the present invention is explained in reference to the above exemplary embodiments. However, the present invention is not limited to those exemplary embodiments. It is possible to apply various changes understandable by those skilled in the art to the configuration and details of the present invention within the scope of the present invention.

For example, while the transmitting device sending data to a receiving device constitutes the throughput estimation device in the above exemplary embodiments, the receiving device may instead constitute the throughput estimation device. Further, a device other than the receiving device and the transmitting device (the base station, a server device, or the like, for example) may instead constitute the throughput estimation device.

Further, while each function of the mobile communication system 1 in each of the above exemplary embodiments is realized by letting the CPU implement a computer program (software), it may alternatively be realized by hardware such as circuits and the like.

Further, while the computer program in each of the above exemplary embodiments is stored in a storage device, it may alternatively be stored in a recording medium readable by a

computer. The recording medium is, for example, a portable medium such as a flexible disk, optical disk, magnetic optical disk, semiconductor memory, or the like.

Further, as other modifications of the above exemplary embodiments, it is possible to adopt any combinations of the above exemplary embodiments and modifications.

<Supplementary Notes>

The whole or part of the exemplary embodiments disclosed above can be described as, but not limited to, the following supplementary notes.

(Supplementary Note 1)

A throughput estimation device comprising:

a wireless link quality information acquisition means for acquiring wireless link quality information denoting a quality of a wireless link established between a mobile station and a base station on a mobile communication network; and

a throughput estimation means for estimating a throughput which is the amount for the mobile station to receive per unit time a data sent by a transmitting device connected communicably with the mobile station via the wireless link, based on the acquired wireless link quality information.

According to this throughput estimation device, it is possible to estimate the throughput with a high accuracy when a data is sent via the wireless link.

(Supplementary Note 2)

The throughput estimation device according to Supplementary Note 1, wherein the throughput estimation means is configured to estimate the throughput based on a mathematical model denoting a relationship between the throughput and the wireless link quality information, and on the acquired wireless link quality information.

(Supplementary Note 3)

The throughput estimation device according to Supplementary Note 2, wherein the mathematical model is constructed by assuming equality between the throughput and a polynomial function with the wireless link quality information as a variable.

Now, there is a comparatively strong correlation between the throughput and the polynomial function with the wireless link quality information as a variable. Therefore, by configuring the throughput estimation device in the above manner, it is possible to estimate the throughput with an even higher accuracy when a data is sent via the wireless link.

(Supplementary Note 4)

The throughput estimation device according to Supplementary Note 3, wherein the mathematical model is constructed by assuming equality between the throughput and a linear function with the wireless link quality information as a variable.

Now, there is a comparatively strong correlation between the throughput and the linear function with the wireless link quality information as a variable. Therefore, by configuring the throughput estimation device in the above manner, it is possible to estimate the throughput with an even higher accuracy when a data is sent via the wireless link.

(Supplementary Note 5)

The throughput estimation device according to Supplementary Note 2, further comprising a transmission rate acquisition means for acquiring a transmission rate which is the amount of the data sent by the transmitting device to the mobile station per unit time, wherein the throughput estimation means is configured to estimate the throughput based on the mathematical model denoting the relationship between the throughput, the wireless link quality information and the transmission rate, on the acquired transmission rate, and on the acquired wireless link quality information.

If the communication bandwidth used by self-traffic changes, then the transmission rate for cross-traffic also changes. Here, the self-traffic is the data sent from the transmitting device to the mobile device. Further, the cross-traffic is the data sent by using a communication pathway sharing at least part of a pathway with the communication pathway from the transmitting device to the mobile station.

Now, there is a comparatively strong correlation between the throughput, wireless link quality information and transmission rate for the self-traffic. Therefore, by configuring the throughput estimation device in the above manner, it is possible to estimate the throughput with an even higher accuracy when the cross-traffic is present.

(Supplementary Note 6)

The throughput estimation device according to Supplementary Note 5, wherein the mathematical model is expressed by an ordinary differential equation for the throughput with an inhomogeneous term of a function taking each of the transmission rate and the wireless link quality information as its variable.

(Supplementary Note 7)

The throughput estimation device according to Supplementary Note 6, wherein the inhomogeneous term is a product of the transmission rate and the polynomial function with the wireless link quality information as a variable.

(Supplementary Note 8)

The throughput estimation device according to Supplementary Note 7, wherein the inhomogeneous term is a product of the transmission rate and the linear function with the wireless link quality information as a variable.

(Supplementary Note 9)

The throughput estimation device according to any one of Supplementary Notes 5 to 8, wherein the mathematical model is constructed by expressing the relationship between the throughput, the wireless link quality information and the transmission rate based on a dynamic model.

Now, the dynamic model successfully expresses the relationship between the throughput, the wireless link quality information and the transmission rate for the self-traffic. Therefore, by configuring the throughput estimation device in the above manner, it is possible to estimate the throughput with an even higher accuracy when the cross-traffic is present.

(Supplementary Note 10)

The throughput estimation device according to Supplementary Note 9, wherein the dynamic model comprises a mobile body movable in a preset moving direction; and at least one of an elastic body deforming in the moving direction as much as the displacement of the mobile body in the moving direction, and a viscous body delaying the movement of the mobile body in the moving direction.

Now, the elastic force of the elastic body denotes better the change of the transmission rate related to the cross-traffic, arising from the change of the transmission rate related to the self-traffic. Therefore, by configuring the throughput estimation device in the above manner, it is possible to estimate the throughput with an even higher accuracy when the cross-traffic is present.

Further, delay time is necessary from the transmitting device changing the transmission rate related to the self-traffic to changing the transmission rate related to the cross-traffic. The resisting force of the viscous body denotes this delay time better. Therefore, by configuring the throughput estimation device in the above manner, it is possible to estimate the throughput with an even higher accuracy when the cross-traffic is present.

(Supplementary Note 11)

The throughput estimation device according to Supplementary Note 10, wherein the mathematical model is constructed by assuming that an external force applied to the mobile body in the moving direction is as great as in accordance with the transmission rate and the wireless link quality information, and by assuming that the throughput is the distance in the moving direction between a preset reference position and the position of the mobile body.

(Supplementary Note 12)

The throughput estimation device according to Supplementary Note 11, wherein the mathematical model is constructed to let the inhomogeneous term express the external force.

(Supplementary Note 13)

The throughput estimation device according to any one of Supplementary Notes 10 to 12, wherein the mathematical model is constructed by assuming that an elastic force generated by the elastic body is as great as the value of the displacement of the mobile body from a force-free position which is the position of the mobile body with the elastic force being zero, multiplied by an elastic coefficient which is a proportionality coefficient, and the elastic force acts in the opposite direction to the direction in which the mobile body has moved from the force-free position.

(Supplementary Note 14)

The throughput estimation device according to any one of Supplementary Notes 10 to 13, wherein the mathematical model is constructed by assuming that a resisting force generated by the viscous body is as great as the velocity of the mobile body moving in the moving direction, multiplied by a viscosity coefficient which is another proportionality coefficient, and the resisting force acts in the opposite direction to the direction in which the mobile body moves.

(Supplementary Note 15)

The throughput estimation device according to any one of Supplementary Notes 1 to 14, further comprising: a throughput acquisition means for acquiring the throughput, and a model parameter estimation means for estimating a model parameter for specifying the mathematical model, based on the acquired throughput and the acquired wireless link quality information.

(Supplementary Note 16)

The throughput estimation device according to any one of Supplementary Notes 1 to 15, wherein the wireless link quality information is a value based on a channel quality indicator (CQI).

(Supplementary Note 17)

The throughput estimation device according to Supplementary Note 16, wherein the wireless link quality information is a value of having put the channel quality indicator through a smoothing process.

(Supplementary Note 18)

A throughput estimation method comprising:
acquiring wireless link quality information denoting a quality of a wireless link established between a mobile station and a base station on a mobile communication network; and
estimating a throughput which is the amount for the mobile station to receive per unit time a data sent by a transmitting device connected communicably with the mobile station via the wireless link, based on the acquired wireless link quality information.

(Supplementary Note 19)

The throughput estimation method according to Supplementary Note 18, wherein the throughput is estimated based on a mathematical model denoting a relationship between the throughput and the wireless link quality information, and on the acquired wireless link quality information.

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(Supplementary Note 20)

The throughput estimation method according to Supplementary Note 19, wherein the mathematical model is constructed by assuming equality between the throughput and a polynomial function with the wireless link quality information as a variable.

(Supplementary Note 21)

The throughput estimation method according to Supplementary Note 19, further comprising acquiring a transmission rate which is the amount of the data sent by the transmitting device to the mobile station per unit time, wherein the throughput is estimated based on the mathematical model denoting the relationship between the throughput, the wireless link quality information and the transmission rate, on the acquired transmission rate, and on the acquired wireless link quality information.

(Supplementary Note 22)

A throughput estimation computer program comprising instructions for causing an information processing device to carry out a process comprising the steps of:

acquiring wireless link quality information denoting a quality of a wireless link established between a mobile station and a base station on a mobile communication network; and estimating a throughput which is the amount for the mobile station to receive per unit time a data sent by a transmitting device connected communicably with the mobile station via the wireless link, based on the acquired wireless link quality information.

(Supplementary Note 23)

The throughput estimation computer program according to Supplementary Note 22, wherein it is configured to cause the information processing device to carry out the process of estimating the throughput based on a mathematical model denoting a relationship between the throughput and the wireless link quality information, and on the acquired wireless link quality information.

(Supplementary Note 24)

The throughput estimation computer program according to Supplementary Note 23, wherein the mathematical model is constructed by assuming equality between the throughput and a polynomial function with the wireless link quality information as a variable.

(Supplementary Note 25)

The throughput estimation computer program according to Supplementary Note 23, wherein it is configured to cause the information processing device to carry out the process further comprising the step of acquiring a transmission rate which is the amount of the data sent by the transmitting device to the mobile station per unit time, and estimating the throughput based on the mathematical model denoting the relationship between the throughput, the wireless link quality information and the transmission rate, on the acquired transmission rate, and on the acquired wireless link quality information.

Further, the present application claims priority from Japanese Patent Application No. 2011-016232, filed on Jan. 28, 2011 in Japan, the disclosure of which is incorporated herein by reference in its entirety.

INDUSTRIAL APPLICABILITY

The present invention is applicable to throughput estimation devices and the like to estimate throughput.

REFERENCE SIGNS LIST

1 Mobile communication system
100 Transmitting device (Throughput estimation device)
101 Data transmission portion
102 Transmission rate acquisition portion

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103 Reception rate acquisition portion

104 Wireless link quality information acquisition portion

105 Model parameter estimation portion

106 Throughput estimation portion

5 200 Receiving device (Mobile station)

201 Data reception portion

202 Received information transmission portion

203 Wireless link quality value acquisition portion

204 Wireless link quality value transmission portion

10 500 Throughput estimation device

501 Wireless link quality information acquisition portion

502 Throughput estimation portion

BS Base station

M1 Mobile body

15 M2, M4 Springs

M3, M5 Dashpots

W1 First wall surface

W2 Second wall surface

The invention claimed is:

1. A throughput estimation device comprising:

a wireless link quality information acquisition unit for acquiring wireless link quality information denoting a quality of a wireless link established between a mobile station and a base station on a mobile communication network;

a throughput estimation unit for estimating a throughput which is the amount for the mobile station to receive per unit time a data sent by a transmitting device connected communicably with the mobile station via the wireless link, based on the acquired wireless link quality information;

wherein the throughput estimation unit is configured to estimate the throughput based on a mathematical model denoting a relationship between the throughput and the wireless link quality information, and on the acquired wireless link quality information; and

wherein the mathematical model is constructed by assuming equality between the throughput and a polynomial function with the wireless link quality information as a variable.

2. The throughput estimation device according to claim 1, wherein the mathematical model is constructed by assuming equality between the throughput and a linear function with the wireless link quality information as a variable.

3. The throughput estimation device according to claim 1, further comprising a transmission rate acquisition unit for acquiring a transmission rate which is the amount of the data sent by the transmitting device to the mobile station per unit time, wherein the throughput estimation unit is configured to estimate the throughput based on the mathematical model denoting the relationship between the throughput, the wireless link quality information and the transmission rate, on the acquired transmission rate, and on the acquired wireless link quality information.

4. The throughput estimation device according to claim 3, wherein the mathematical model is expressed by an ordinary differential equation for the throughput with an inhomogeneous term of a function taking each of the transmission rate and the wireless link quality information as its variable.

5. The throughput estimation device according to claim 4, wherein the inhomogeneous term is a product of the transmission rate and the polynomial function with the wireless link quality information as a variable.

6. The throughput estimation device according to claim 5, wherein the inhomogeneous term is a product of the transmission rate and the linear function with the wireless link quality information as a variable.

7. The throughput estimation device according to claim 3, wherein the mathematical model is constructed by expressing

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the relationship between the throughput, the wireless link quality information and the transmission rate based on a dynamic model.

8. The throughput estimation device according to claim 7, wherein the dynamic model comprises a mobile body movable in a preset moving direction; and at least one of an elastic body deforming in the moving direction as much as the displacement of the mobile body in the moving direction, and a viscous body delaying the movement of the mobile body in the moving direction.

9. The throughput estimation device according to claim 8, wherein the mathematical model is constructed by assuming that an external force applied to the mobile body in the moving direction is as great as in accordance with the transmission rate and the wireless link quality information, and by assuming that the throughput is the distance in the moving direction between a preset reference position and the position of the mobile body.

10. The throughput estimation device according to claim 9, wherein the mathematical model is constructed to let the inhomogeneous term express the external force.

11. The throughput estimation device according to claim 8, wherein the mathematical model is constructed by assuming that an elastic force generated by the elastic body is as great as the value of the displacement of the mobile body from a force-free position which is the position of the mobile body with the elastic force being zero, multiplied by an elastic coefficient which is a proportionality coefficient, and the elastic force acts in the opposite direction to the direction in which the mobile body has moved from the force-free position.

12. The throughput estimation device according to claim 8, wherein the mathematical model is constructed by assuming that a resisting force generated by the viscous body is as great as the velocity of the mobile body moving in the moving direction, multiplied by a viscosity coefficient which is another proportionality coefficient, and the resisting force acts in the opposite direction to the direction in which the mobile body moves.

13. The throughput estimation device according to claim 1, further comprising: a throughput acquisition unit for acquiring the throughput, and a model parameter estimation unit for estimating a model parameter for specifying the mathematical model, based on the acquired throughput and the acquired wireless link quality information.

14. The throughput estimation device according to claim 1, wherein the wireless link quality information is a value based on a channel quality indicator (CQI).

15. The throughput estimation device according to claim 14, wherein the wireless link quality information is a value of having put the channel quality indicator through a smoothing process.

16. A throughput estimation method comprising:
acquiring wireless link quality information denoting a quality of a wireless link established between a mobile station and a base station on a mobile communication network; and
estimating a throughput which is the amount for the mobile station to receive per unit time a data sent by a transmitting device connected communicably with the mobile station via the wireless link, based on the acquired wireless link quality information;
wherein the throughput estimation unit is configured to estimate the throughput based on a mathematical model denoting a relationship between the throughput and the wireless link quality information, and on the acquired wireless link quality information; and
wherein the mathematical model is constructed by assuming equality between the throughput and a polynomial function with the wireless link quality information as a variable.

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17. The throughput estimation method according to claim 16, wherein the throughput is estimated based on a mathematical model denoting a relationship between the throughput and the wireless link quality information, and on the acquired wireless link quality information.

18. The throughput estimation method according to claim 17, wherein the mathematical model is constructed by assuming equality between the throughput and a polynomial function with the wireless link quality information as a variable.

19. The throughput estimation method according to claim 17, further comprising acquiring a transmission rate which is the amount of the data sent by the transmitting device to the mobile station per unit time, wherein the throughput is estimated based on the mathematical model denoting the relationship between the throughput, the wireless link quality information and the transmission rate, on the acquired transmission rate, and on the acquired wireless link quality information.

20. A non-transitory computer-readable medium storing a throughput estimation computer program comprising instructions for causing an information processing device to carry out a process comprising the steps of:

acquiring wireless link quality information denoting a quality of a wireless link established between a mobile station and a base station on a mobile communication network; and

estimating a throughput which is the amount for the mobile station to receive per unit time a data sent by a transmitting device connected communicably with the mobile station via the wireless link, based on the acquired wireless link quality information;

wherein the throughput estimation unit is configured to estimate the throughput based on a mathematical model denoting a relationship between the throughput and the wireless link quality information, and on the acquired wireless link quality information; and

wherein the mathematical model is constructed by assuming equality between the throughput and a polynomial function with the wireless link quality information as a variable.

21. The non-transitory computer-readable medium storing the throughput estimation computer program according to claim 20, wherein it is configured to cause the information processing device to carry out the process of estimating the throughput based on a mathematical model denoting a relationship between the throughput and the wireless link quality information, and on the acquired wireless link quality information.

22. The non-transitory computer-readable medium storing the throughput estimation computer program according to claim 21, wherein the mathematical model is constructed by assuming equality between the throughput and a polynomial function with the wireless link quality information as a variable.

23. The non-transitory computer-readable medium storing the throughput estimation computer program according to claim 21, wherein it is configured to cause the information processing device to carry out the process further comprising the step of acquiring a transmission rate which is the amount of the data sent by the transmitting device to the mobile station per unit time, and estimating the throughput based on the mathematical model denoting the relationship between the throughput, the wireless link quality information and the transmission rate, on the acquired transmission rate, and on the acquired wireless link quality information.